Journal
of
The Franklin Institute
Devoted to Science and the Mechanic Arts

Vol. 212 DECEMBER, 1931 No. 6

THE CATHODE RAY OSCILLOGRAPH.*

BY

J. B. JOHNSON, Ph.D.,

Research Physicist, Bell Telephone Laboratories.

In our complicated life, we find that we need a great many aids to our primary sense organs. The processes of the modern world demand that we make correct estimates of things that are too large or too small, too intense or too feeble, for our poor senses. We have balances to give us the weight of masses too heavy for us to lift or too small to be felt. Telescopes enable us to see far-off objects, microscopes very small objects. Our ears are supplemented by telephones that put us within earshot of almost all the civilized world. For electric currents we have ammeters to measure currents so large as to destroy us in a second, and galvanometers that measure currents far too small for us to feel as a shock. Taste and smell have not yet been supplied with artificial aids, but that may come some day.

For recording long times we have clocks and calendars; for making a record of happenings that take place in a time too short for us to think of, we use oscillographs.

There are a number of different types of oscillographs in use, all of them electrical in nature. The kind that I am going to discuss involves a stream of cathode rays, and it is there-

* Presented at a meeting held Thursday, December 4, 1930.

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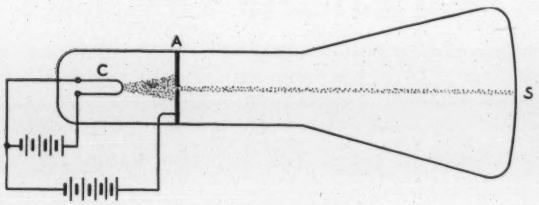
fore called the cathode ray oscillograph. The principle of its operation is quite simple. We have two electrodes in an elongated, evacuated glass tube as in Fig. 1; one of them may

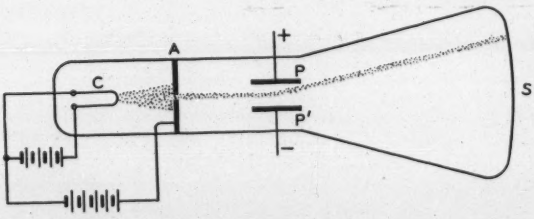
FIG. 1.



Schematic of cathode ray tube.

be a heated filament, the other a plate with a small hole in it. When a potential is applied between the electrodes, making the filament cathode and the plate anode, the electrons emitted by the hot filament are drawn to the anode. Some of them pass through the fine hole in the anode and continue as a thin pencil of electrons, a cathode ray, down the length of the tube. At the end of the tube is a screen of fluorescent materials, which shines brightly at the point where the ray strikes it. We can therefore see where the ray ends on the screen. Another pair of electrodes in the form of two plates P and P_1 is

FIG. 2.

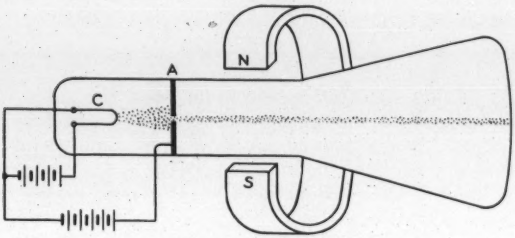


Tube with electrostatic deflection.

introduced so that the cathode ray passes between them (Fig. 2). Now, by a battery or otherwise, we apply a voltage between the plates, so that one is positive with respect to the

other. The electrons of the ray, being negative charges, are during their passage between the plates drawn toward the positive plate and emerge in a different direction because of the applied voltage. Similarly, a magnetic field applied by the magnet *N–S*, across the path of the ray and in the plane of the paper as in Fig. 3, makes the ray emerge in a direction

FIG. 3.



Tube with magnetic deflection.

out from the page. The amount of the deflection is a measure of the strength of the applied magnetic or electric field. We have, then, in this cathode ray a pointer which tells the magnitude of the field that deflects it. It is, furthermore, a pointer that is almost without mass and sluggishness, it is almost not a material pointer. It can therefore follow variations in the applied field that are very rapid, as we shall see presently. Because of this property the instrument has been used extensively for studying the electrical phenomena of such a range of subjects as power machinery, telephone apparatus, radio transmission and electric surges. One of the more dramatic recent applications has been the investigation of lightning, probably the most important work on lightning since its electrical nature was discovered by Benjamin Franklin 180 years ago.

Let us examine the operation of the tube more closely. The speed of the electrons as they emerge from the aperture in the anode can be determined from the energy equation,

$$1/2mv^2 = eV,$$

the energy of motion equals the total work done on the electron by the field between cathode and anode. V is the potential

between cathode and anode, e the electric charge constituting the electron, m its mass and v its speed. Solving for the speed we have the relation between the speed and the driving voltage,

$$v = \sqrt{2\frac{e}{m}V}.$$

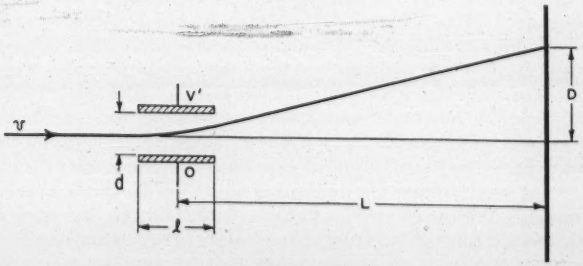
The value of e/m is known to be 1.77×10^7 e.m.u., the volt is 10^8 e.m.u. and the velocity of the electrons is thus

$$v = 5.95 \times 10^7 \sqrt{V} \text{ cm./sec.}$$

If the driving potential is 300 volts, then the speed of the electrons is given as roughly 1×10^9 cm./sec. or 6000 miles per second. For a tube 20 cm. long an electron travels from the deflector plates to the screen in $20/10^9 = 1/50{,}000{,}000$ sec. If the applied voltage is 30,000 volts the speed is very nearly ten times as great as with 300 volts, it is 1/3 the velocity of light. A change of direction of the ray induced at the deflector plates is therefore transmitted to the end of the ray in a very short time, and the ray can follow faithfully potential variations at the plates that are very rapid.

Let us see how the ray responds to voltage applied to the plates. The ray normally travels with a speed v along the tube. Referring to Fig. 4, the ray now passes between two

FIG. 4.



Electrostatic deflection.

plates of length l and separation d, between which a potential difference V' is maintained. While the ray is passing between

the plates the electrons are subject to an acceleration,

$$a = \frac{e}{m}E = \frac{e}{m}\frac{V'}{d}.$$

This continues during the time $t = l/v$. The transverse velocity acquired is therefore

$$v' = at = \frac{e}{m}\frac{V'}{d}\frac{l}{v}.$$

The ray then travels on in a straight line to the screen which it meets at a distance D from the normal position. The deflection D bears the same relation to the length of the beam, from the center of the deflecting plates, as the transverse velocity bears to the longitudinal.

$$\frac{D}{L} = \frac{v'}{v} = \frac{e}{m}\frac{V'}{d}\frac{l}{2\frac{e}{m}V} = \frac{1}{2}\frac{l}{d}\frac{V'}{V}.$$

$$D = \frac{1}{2}\frac{lL}{d}\frac{V'}{V}.$$

This brings out an interesting point in connection with the design of the deflector plates. For high sensitivity the plates should be long and close together, but the plates must not cut the path of the deflected ray. If we want to get a certain maximum deflection D with a tube of a certain length L, then the relation of spacing to length of the plates must be

$$\frac{d}{l} = \frac{D}{L},$$

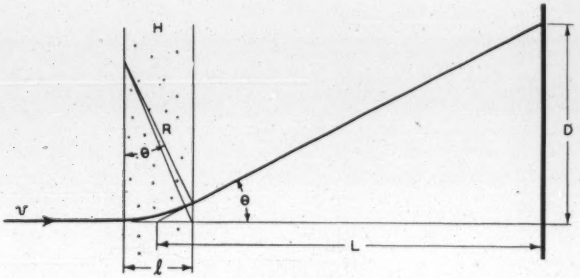
as can easily be seen from Fig. 4. When this condition is satisfied it makes little difference in the sensitivity whether the plates are large and far apart or small and close together.

The magnetic sensitivity of the tube is more uncertain only because the boundaries of the magnetic field are usually less well defined than those of the electric field. One form of the derivation will be given here. If the ray generated by the

driving voltage V passes for a distance l (Fig. 5) through a region in which there is a transverse magnetic field of strength H, the path of the beam is an arc of a circle whose radius is

$$R = \frac{mv}{eH} = \frac{1}{H}\sqrt{\frac{2mV}{e}}.$$

FIG. 5.



Magnetic deflection.

When the ray leaves the magnetic region it proceeds in a straight line to the screen, where the total deflection from the normal is D. If the angular deflection θ is not great then we have, very nearly,

$$\tan\theta = \frac{D}{L} \doteq \frac{l}{R} = lH\sqrt{\frac{e}{2mV}}$$

and hence

$$D \doteq lLH\sqrt{\frac{e}{2mV}}.$$

In practical units instead of electromagnetic the expression becomes

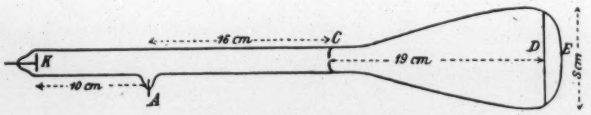
$$D \doteq .3lLH/\sqrt{V}.$$

Having now described in an elementary way how the cathode ray oscillograph works, let me turn to the story of the development of the tube.[1] The first reference I have seen to

[1] More detailed chronicles of the development of the tube have been made by H. Hausrath, "Apparatus and Technique for Producing and Recording Curves of Alternating Currents and Electrical Oscillations," "*Helios*," 1912; and by MacGregor-Morris and Mines, "Measurements in Electrical Engineering by Means of Cathode Rays," *Jl. Inst. El. Eng.*, 63, p. 1056, 1925.

the idea that a cathode ray might be used to indicate magnetic field dates to 1894, when Hess,[2] in France, suggested the use of such a tube as a curve tracer. The first application of the idea, however, was made by Ferdinand Braun [3] in 1897, and after him the instruments have been called Braun tubes.

FIG. 6.

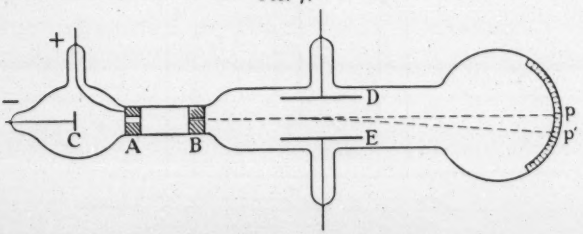


The first cathode ray oscillograph.

The tube of Braun was quite simple (Fig. 6). It had a flat disc cathode, a wire in a side tube as anode, a pierced diaphragm to limit the beam and a fluorescent screen of zinc sulphide. It contained air at low pressure. Current from an electrostatic machine produced a discharge in the residual gas in the tube, from which emanated the cathode rays through the aperture in the diaphragm.

It is of interest that the invention of the tube took place before the nature of cathode rays was understood. It was in the same year that J. J. Thomson in England and W. Kaufmann in Germany, each using a tube that was almost identical with the Braun tube, determined that cathode rays have mass as well as charge. Thomson's tube [4] is shown in Fig. 7.

FIG. 7.

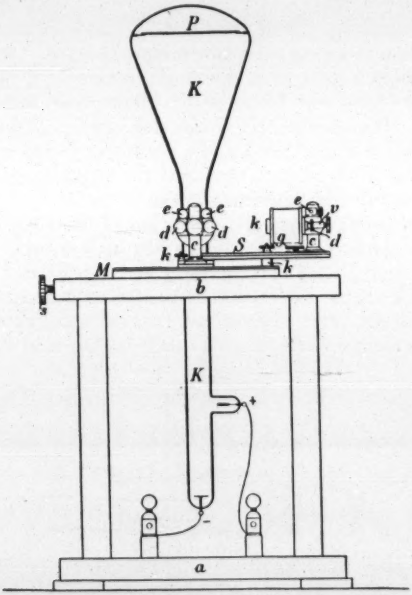


Tube for measuring e/m. J. J. Thomson, 1897.

[2] Hess, A., Compt. Rend., **119**, p. 57, 1894.
[3] Braun, Ferdinand, *Wied. Ann.*, **60**, p. 552, 1897.
[4] Thomson, J. J., *Phil. Mag.*, **44**, p. 293, 1897.

The Braun tube immediately found many applications. One of the most fruitful fields for it was its use by Prof. Zenneck in studying radio circuits and the transmission of radio waves. From Prof. Zenneck and his school there are still papers coming out on work done by means of the Braun tube. The tube was introduced in this country very early. Prof. H. J. Ryan, then at Cornell, in 1903 described measurements on high voltage power circuits, and similar work has appeared occasionally ever since from Professor Ryan's hand.

FIG. 8.

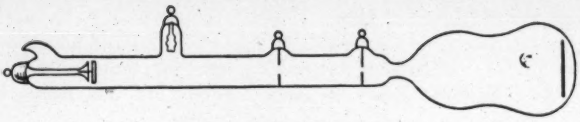


Ebert and Hoffmann, 1898—tube by Geissler.[5]

After the invention of the tube there were a number of improvements that made it more convenient and its operation more reliable. Figures 8–12 show some of the many designs

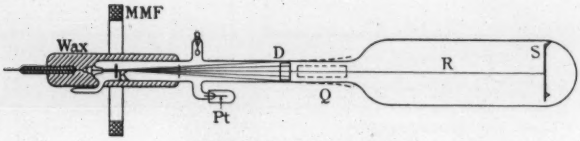
[5] Ebert and Hoffmann, *E. T. Z.*, 19, p. 405, 1898.

FIG. 9.



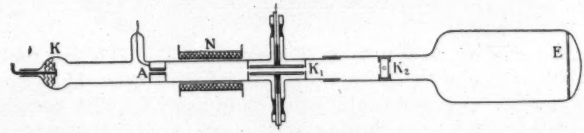
MacGregor-Morris—tube by Cossor.[6]

FIG. 10.



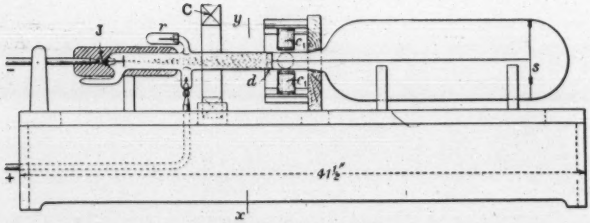
Tube by Muller-Uri-Ryan, 1903.[7]

FIG. 11.



Roschansky, 1911.[8]

FIG. 12.

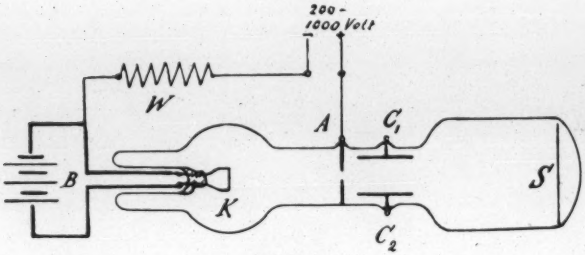


Broughton, 1913—tube by Max Kohl.[9]

[6] MacGregor-Morris, *Engineering*, **73**, p. 754, 1902.
[7] Ryan, H. J., Am. Inst. El. Eng., *Trans.*, **22**, p. 539, 1903.
[8] Roschansky, D., *Ann. d. Phys.*, **36**, p. 281, 1911.
[9] Broughton, H. H., *Electrician*, **72**, p. 171, 1913.

of tubes of this time. In 1905 Wehnelt [10] suggested the use of a hot, lime coated filament, which he had found a couple of years earlier to be a strong emitter of electrons and which was the basis of the present day oxide coated filaments in vacuum tubes. Wehnelt made up such a tube (Fig. 13) which he

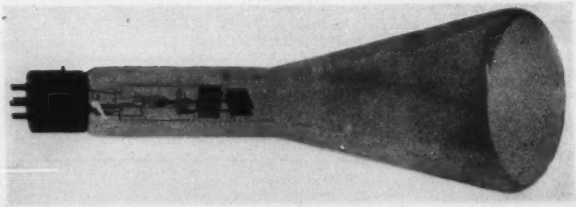
FIG. 13.



Wehnelt, 1905.

could operate on the 220 volt power circuit. This was probably the first practical application of the oxide coated filament. A number of experimental tubes were made up with hot filaments in the years following, but almost twenty years were to elapse before a really successful tube with hot cathode and low voltage was developed. This was the Western Electric 224

FIG. 14.



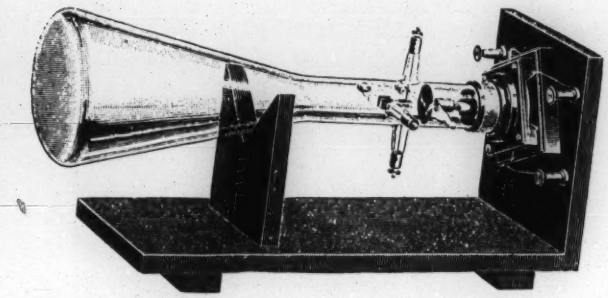
Western Electric tube.

[10] Wehnelt, A., *Phys. Zeit.*, 6, p. 732, 1905.

tube [11] shown in Fig. 14. Another tube of this type, by von Ardenne and Hartel,[12] is illustrated in Fig. 15.

After Braun and Wehnelt, the most notable change in structure was made by A. Dufour [13] in France in 1914. Up to

FIG. 15.

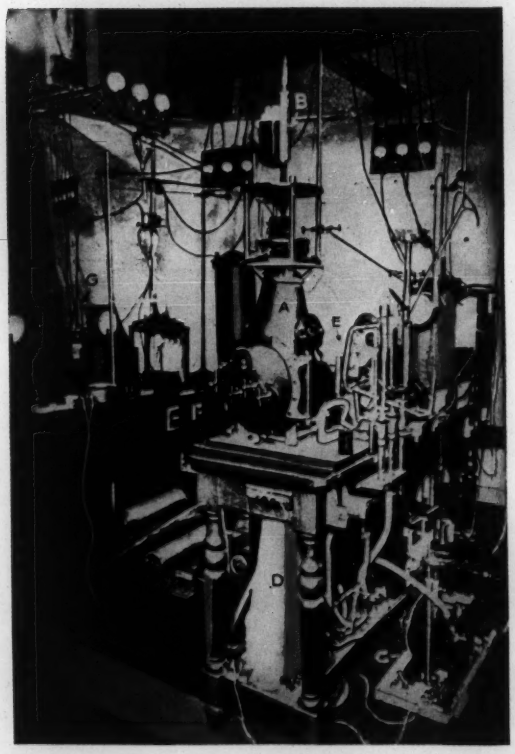


Von Ardenne-Hartel, 1930—tube by Leybold's Nachfolger.

that time permanent records of the pattern on the fluorescent screen were made by means of a camera. This usually meant that the pattern for a rapid phenomenon had to be repeated many times before the photographic plate was exposed enough. Dufour omitted the fluorescent screen and instead placed the photographic plate inside the tube so that the cathode ray could play directly on it. When the cathode rays strike the photographic emulsion directly a record can be traced in a much shorter time than when the intermediary light from a fluorescent screen is focused by a lens on the photographic plate. Placing the photographic plates internally of course involved a number of complications, such as mechanism for moving the plates inside the evacuated tube, means for inserting and taking out the plates, and pumps for producing and maintaining the vacuum. The old glass structure is largely abandoned in these tubes, and metal is substituted. The applied voltage is very high, of the order of 50,000 volts. This

[11] Johnson, J. B., *Jl. Am. Opt. Soc.*, and *R. S. I.*, **6**, p. 701, 1922.
[12] Hartel, H. von, *Zeit. f. Hochfr. Techn.*, **34**, p. 227, 1929.
[13] Dufour, A., *Compte Rend.*, **158**, p. 1339, 1914.

FIG. 16.



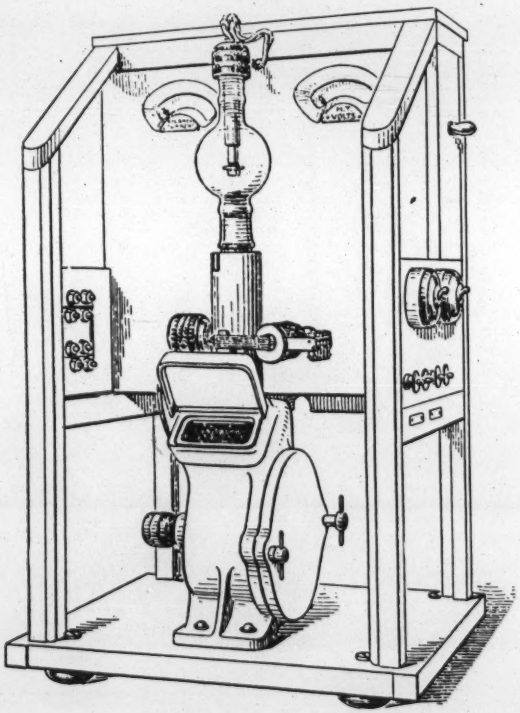
Dufour oscillograph of 1923.[14]

[14] Dufour, A., Oscillographe Cathodique, *Etienne Chiron*, Paris, 1923.

makes a rather formidable piece of apparatus (Fig. 16), but quite a useful one.

In the last few years several different tubes of this type have been developed. Aside from Dufour's tube, there are those of Rogowski in Germany, Wood in England, Berger in Switzerland, Norinder in Sweden, The Westinghouse Co. and the General Electric Co. in this country (Figs. 17–20). All of

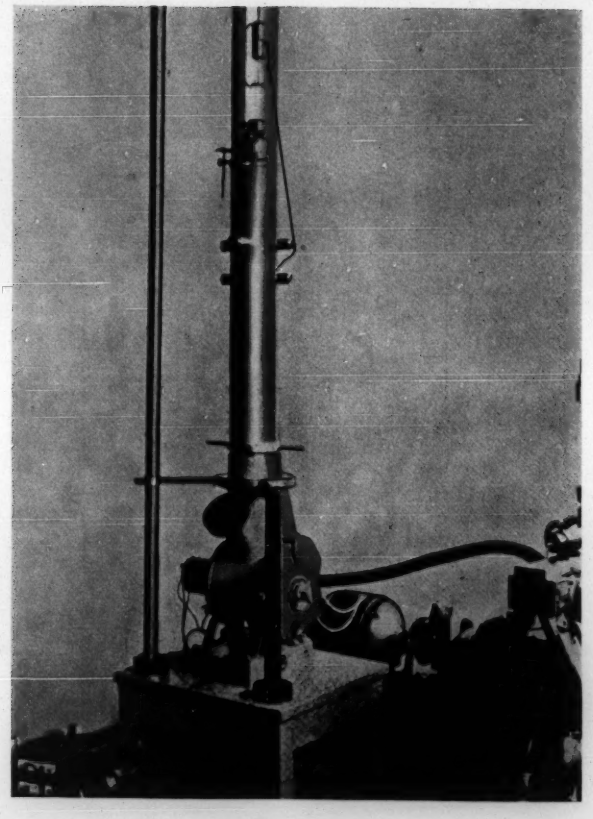
FIG. 17.



Wood, 1923.[15]

[15] Wood, A. B., *Phys. Soc. Lond. Proc.*, **35–2**, p. 109, 1923.

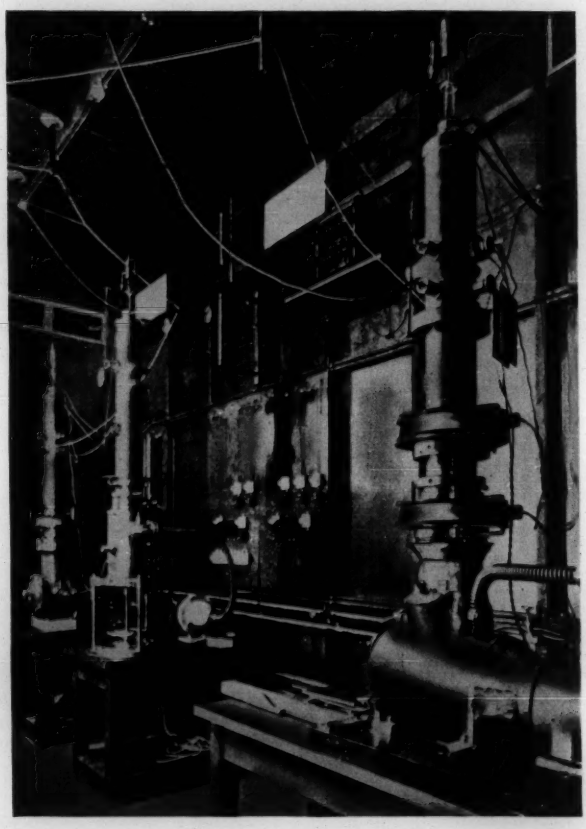
FIG. 18.



Westinghouse-Norinder, 1928.[18]

[18] Norinder, H., *A. I. E. E. Trans.*, **47**, p. 446, 1928.

FIG. 19.

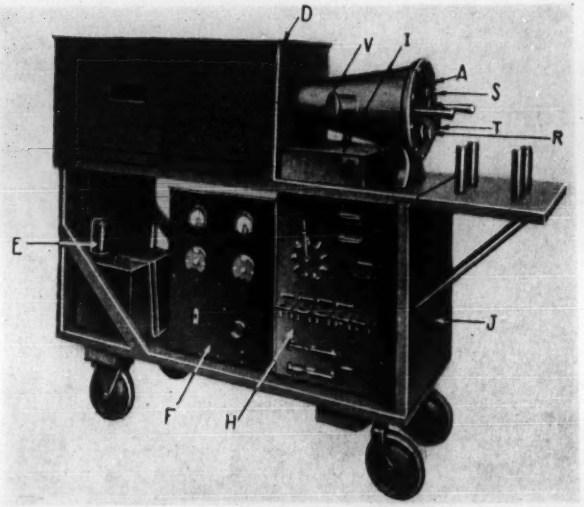


Norinder, 1930—group of oscillographs.[17]

[17] Norinder, H., *Zeits. f. Phys.*, 63, p. 672, 1930.

them involve complicated tubes and control circuits. Some tubes are made to operate during a single peak of a 60 cycle wave. With others there are ingenious switching devices that

FIG. 20.



General Electric, 1928.[18]

start the tube operating at the very beginning of the electrical impulse to be studied, and the tube then proceeds to record the rest of the impulse. When we consider that the impulse may be a stroke of lightning on a transmission line, we realize that there are some things that are "faster than greased lightning."

In the last couple of years a further step has been made by Max Knoll.[19] He seems to have simplified the operation of the tube considerably by attaching on the end of his tube a

[18] Lee, E. S., *G. E. Rev.*, 31, p. 404, 1928.
[19] Knoll, Max, *Zeits. f. Tech. Phys.*, 10, p. 28, 1929.

thin window in the manner of Dr. Coolidge's cathode ray tube. In this way the photographic plate on the outside of the tube is exposed to the pencil of cathode rays that has come through the thin window of metal or of cellophane.

We have, then, three general classes of cathode ray oscillographs: First those that resemble the original Braun tube, still in limited use, comprising a glass tube with a fluorescent screen, and a relatively high operating voltage; second the tubes of the Dufour type that I have just described, with direct recording on the photographic plate or film; and third, tubes with a hot cathode, with a relatively low operating voltage.

Of this last type is the Western Electric No. 224 Cathode Ray Oscillograph. Since this is the tube with which I have had more direct contact I wish to discuss some problems of its development and operation.

The design of the tube shown in Fig. 14 is now fairly familiar,* and I will describe it only as I describe the reason for the various features.

First we wanted a convenient tube to operate on the batteries of an ordinary vacuum tube. The thermionic filament cathode was therefore required. The anode is a metal tube placed a short distance from the cathode and between them is a metal disc with a perforation through which the electrons pass to the anode. These electrodes are represented respectively by the letters *C*, *A* and *D* in Fig. 21. The electrons flow

FIG. 21.

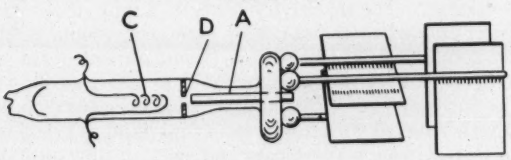


Diagram of electron gun.

* Since the paper was read the tube has been altered in certain respects. The glass enclosure for the filament has been replaced by one of metal, and the anode and deflector plates are supported on machined insulating blocks. These changes make the structure more rugged and insure more perfect alignment of the parts.

The end of the bulb has been changed so as to present a cylindrical surface instead of a spherical one, thus permitting more intimate contact between the fluorescent screen and a photographic film when contact photographs are made.

from the cathode to the inside of the anode and some of them pass through and form the electron beam. Now, for reasons to be mentioned presently, there is some gas in the tube and this puts two requirements on the structure of the electron gun. First, the gas would permit considerable ionization in the tube if the electrons were permitted to pass into it. Most of the current would go around the disc and to the outside of the anode. The cathode and anode are therefore enclosed in a small tube, having dimensions less than the mean free path of electrons in the gas so that no appreciable ionization can build up. There is some ionization, however, in the space between the cathode and anode, and the positive ions produced tend to bombard the filament. If the filament is directly exposed to this bombardment the oxide coating is worn off, as in a sand blast, in a matter of two or three hours. The filament is therefore wound in the shape of a helix which is mounted coaxially with the anode and the perforation in the disc so as to be out of the direct path of the ions. In this way the filament is made to last several hundred hours of operation.

This completes the internal parts of the electron gun. Externally it has mounted on it two pairs of deflector plates that control the direction of the electrons after they leave the gun. In order to prevent any large difference of potential between the anode and deflector plates, one plate of each pair is connected directly to the anode, and only the other plate has the variable potential impressed on it. As for size and separation, the plates are designed to give maximum sensitivity for a given full deflection. The sensitivity is about 1 mm. deflection for each volt applied to the deflector plates, or 1 mm. for each ampere turn in a pair of small coils placed outside of the tube. These figures are for the normal driving potential of 300 volts.

The flattened end of the bulb, on which the electron beam impinges is covered with a fluorescent material. The powder is a mixture of zinc orthosilicate and calcium tungstate, both specially prepared for fluorescence. The zinc silicate produces a green light of high visibility and the tungstate a blue light of high photographic activity, so that with the mixture the same tubes can be used efficiently for both visual and photographic observations.

As said before, there is some gas in the tube. One purpose

of the gas is to produce a small amount of ionization in the tube which prevents any unduly large charges from accumulating on the glass walls and screen. Electrons deposited on the glass are neutralized by positive ions produced in the gas. An electron current equal to the current in the beam drifts back through the gas to the anode. The chief result of this drift of electrons is that a negative space charge is formed in the tube which decreases the speed of the electrons before they strike the screen as if the driving potential had been lowered by about 50 volts.

The other and more important purpose of the gas is to bring the electrons of the beam to a sharper focus at the screen. The beam is diffuse for two reasons, first because it is originally divergent, and secondly because of the natural electrostatic repulsion that tends to force the electrons apart. The gas serves to overcome these actions in the following way: As the beam of electrons travels down the length of the tube, some electrons collide with atoms of the gas and separate the atom into an electron and a positive ion. The impact of the electron does little to displace the massive positive ion from the position it temporarily occupies while two electrons are immediately shot out of the path. The result is a column of positive ionization down the length of the beam, with a negative space charge surrounding it. This produces a radial electrostatic field which tends to bend the path of the outer electrons of the beam inward toward the centre. The magnitude of this action depends on the degree of the differential ionization. This again, is the greater the higher the gas pressure and the greater the current in the beam. The gas pressure must be low enough so that the larger fraction of the electrons reach the screen, and then the current in the beam must be such as to produce the desired focusing action. The heavier the ions the lower can the pressure be. The condition for a focus then involves the kind and pressure of gas, the speed of the electrons, the current in the beam and the length of the tube. In the 224 tube, with argon at the pressure of .01 mm. the focusing occurs at about 20 microamperes in the beam. Less current makes a large unfocused spot, more current produces a focus before the screen is reached, with consequent spreading of the spot again. Hence it is that the spot

on the fluorescent screen is focused by adjusting the heating current of the cathode.

Besides focusing the electrons and preventing the accumulation of charges in the tube, the gas plays various other rôles. One very curious effect of the gas is that it decreases the sensitivity of the tube at small deflecting voltages. When uniformly varying voltage is applied to a pair of deflector plates so as to move the spot across the screen, the spot seems to hesitate for an instant at the centre of the screen, appearing to be brighter there. The effect has always been observed but particular attention has recently been given to it by Professor Bedell. The explanation has to do with space charge between the deflector plates. The beam of electrons produces slowly moving positive ions and electrons in the gas along its path between the plates. When a voltage is applied to the plates, the positive ions travel from the beam toward the negative plate and an equal number of the electrons travel toward the positive plate. The space charge set up by the electrons and ions produces an electric field opposing that created by the applied voltage. The greatest space charge occurs near the negative plate where the sluggish positive ions flow. The space midway between the plates remains nearly field free and there is little deflection of the beam until the voltage is greater than that at which all of the ions produced are drawn to the plate. Calculation agrees with observation that this voltage is 2 to 3 volts on either side of zero.

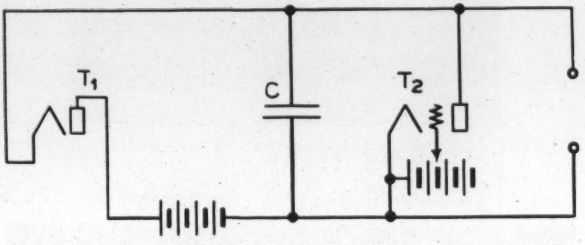
Having now described the operation and structure of some of the oscillographs, I should like to say something more about their uses.

The cathode ray oscillograph is essentially a curve tracer that plots out in rectangular coördinates the relation between two quantities represented by the fields between the deflector plates. Often one of these quantities is time, as in the ordinary moving mirror oscillograph, while the other is some electrical quantity. We then say that we plot a wave shape. We must then have a way of making the spot move at a uniform rate. One of the simplest and most reliable ways of producing a linear time axis,[20] at least for low voltage tubes, employs two thermionic tubes to control the charge in a condenser

[20] A. L. Samuel, *Rev. Sci. Inst.* **2**, p. 532, 1931.

as shown in Fig. 22. One tube, a simple two-electrode tube T_1, limits the charging current of the condenser C so that the voltage across the condenser rises linearly with time according to the equation $V = Cit$. The second tube T_2 is filled with gas and has the property of passing current only when the voltage across it reaches a certain value, which in turn is con-

FIG. 22.



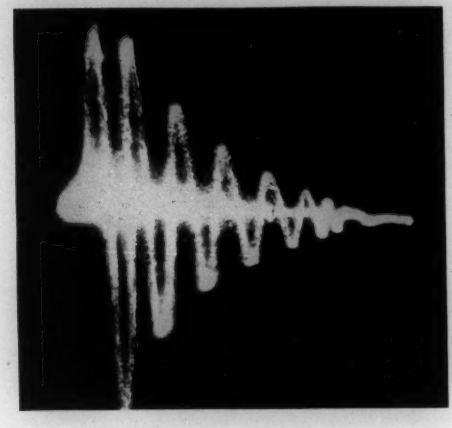
Thermionic tube "sweep circuit."

trolled by the grid potential. When the condenser voltage reaches this value the tube operates to discharge the condenser suddenly, and then the uniform charging process begins over again. The condenser voltage applied to one pair of plates of the oscillograph tube makes the spot travel over the screen at a uniform rate in one direction, returning much faster in the other direction. This process may be repeated once a second, or many thousand times a second, depending on the frequency of the wave that is being studied.

In Figs. 23–29 are shown a number of records plotted on a time basis. Figures 23–25 were made with the Western Electric tube, Figs. 26–27 with the Dufour oscillograph, and Figs. 28–29 on an oscillograph of the type of Rogowski.

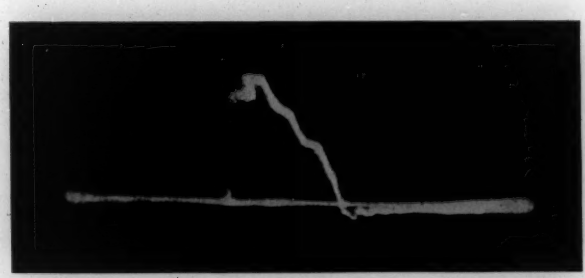
Another way to use the tube is to have it plot the relation between two quantities irrespective of time. As a simple case we may take the current *vs.* voltage curve of a resistance through which an alternating current is flowing. The spot travels back and forth along a straight line, the slope of which measures the reciprocal of the resistance (Fig. 30*a*). If in-

FIG. 23.



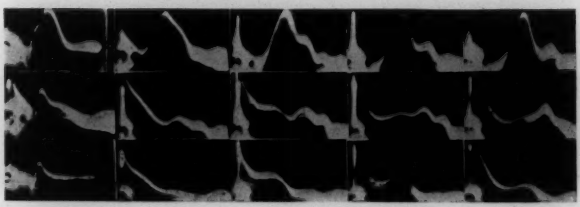
Discharge of condenser through inductance.

FIG. 24.



Discharge of condenser through chattering contact.

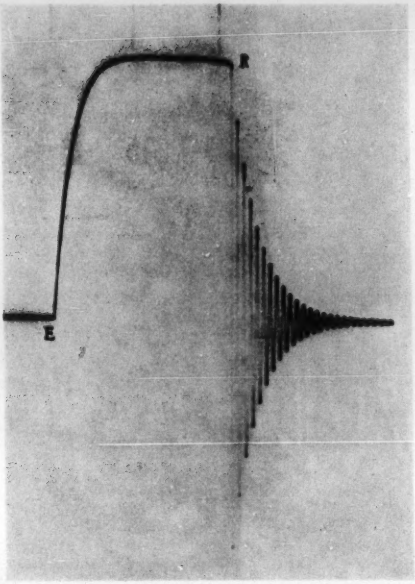
FIG. 25.



Action current of a stimulated frog-nerve.[21]

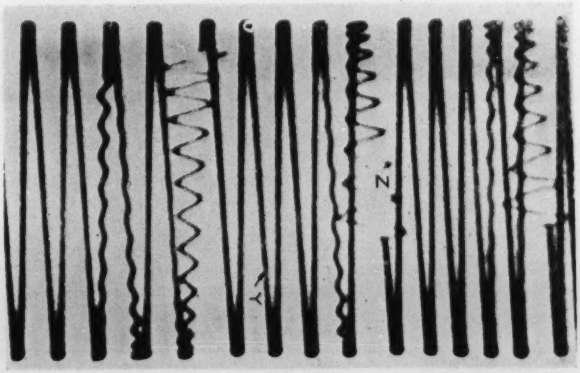
[21] Gasser and Erlanger, *Am. Jl. Physiol.*, 73, p. 613, 1925.

FIG. 26.



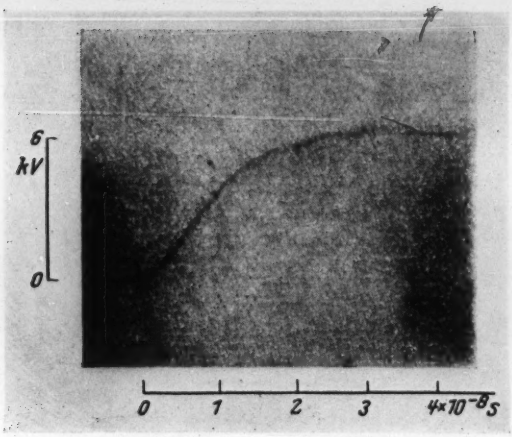
Make of current through direct contact and break through tuned circuit—Dufour.[14]

FIG. 27.



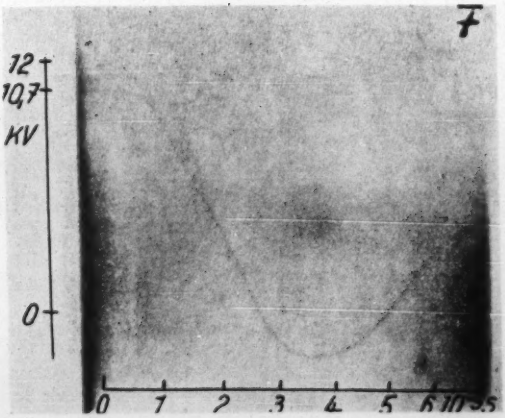
Wave shape at 8,500,000 cycles—Dufour.[14]

FIG. 28.



Front of a voltage wave traveling on a conductor.[22]

FIG. 29.

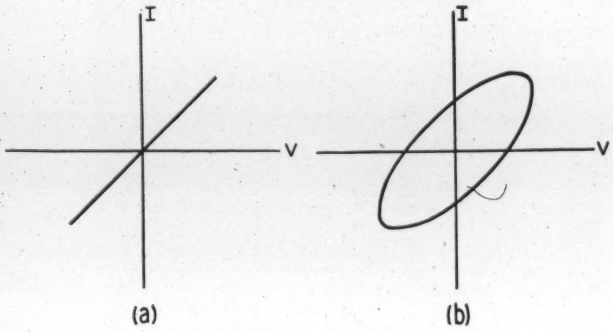


Initiation of spark in a gas.[23]

[22] Krug, W., *E. T. Z.*, 51, p. 605, 1930.
[23] Krug, W., *Zeits. f. Techn. Phys.*, 11, p. 153, 1930.

ductance is added to the resistance the spot does not come down on the same line it went up; an ellipse results, the spread of which tells us the amount of the inductive impedance

FIG. 30.



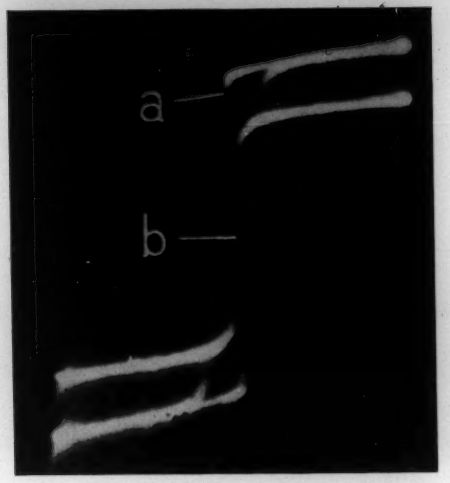
Diagrams of current voltage-curves.

(Fig. 30*b*). This method of operation has a wide variety of applications. Instead of the resistance, for instance, we may have a gas discharge device of which we want to know the properties. One of the applications of this method is the production of hysteresis curves of the ferromagnetic materials[24] (Fig. 31). Figure 32 illustrates the application of the method to the study of distortion in an amplifier.

Suppose we apply to each pair of deflector plates a voltage from each of two different oscillators. If the oscillators make exactly the same number of vibrations per second, then the pattern on the tube remains stationary, but if the frequency of the oscillators differ ever so little the pattern goes through gradual changes according to the different phase relations. This is one of the most sensitive means we have for comparing and calibrating accurate oscillators, and we may call it the Lissajous figure method. Figure 33 shows the appearance of some of these stationary Lissajous patterns.

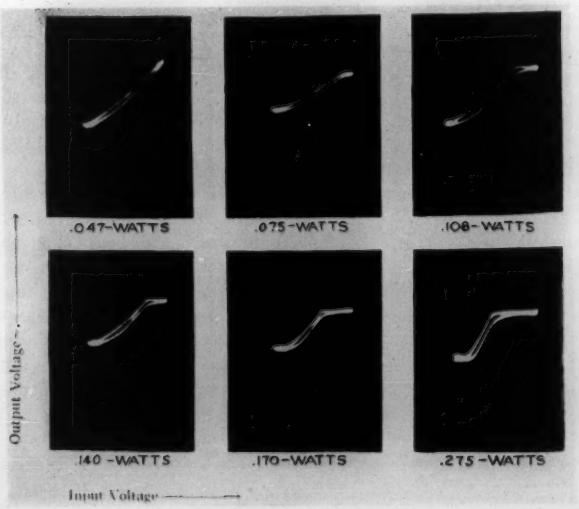
[24] Johnson, J. B., *Bell System Technical Jl.*, **8**, p. 286, 1929.

FIG. 31.



Hysteresis curves, (*a*) of iron, (*b*) of permalloy.

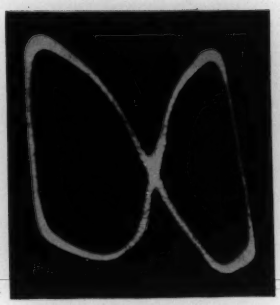
FIG. 32.



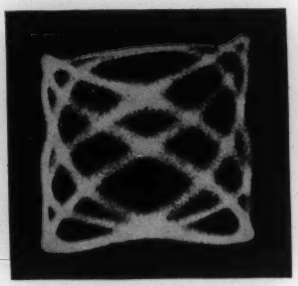
Distortion in vacuum tube amplifier.[25]

[25] Willis and Melhuish, *Bell System Technical Jl.*, 5, p. 573, 1926.

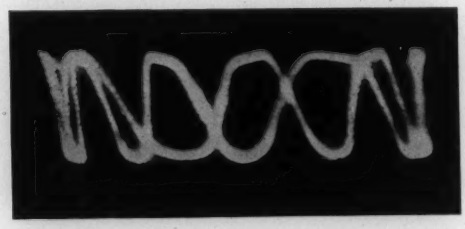
FIG. 33.



(*a*) Ratio 2 : 1.



(*c*) Ratio 5 : 4.

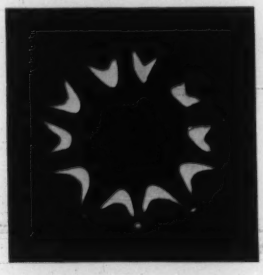


(*b*) Ratio 8 : 1.

Frequency comparison.

Another method of comparing the frequency of oscillators has been called the gear-wheel method. In this method the voltage from the low frequency source is split into two equal components 90° apart in phase. These two voltages are applied to the deflector plates, producing a stationary circle on the screen. The voltage from the oscillator of higher frequency is introduced in the circuit between the cathode and anode of the tube so that the sensitivity of the tube is varied in accordance with the higher frequency. The circle is distorted into a gear-wheel shape as shown in Fig. 34, provided that the

FIG. 34.



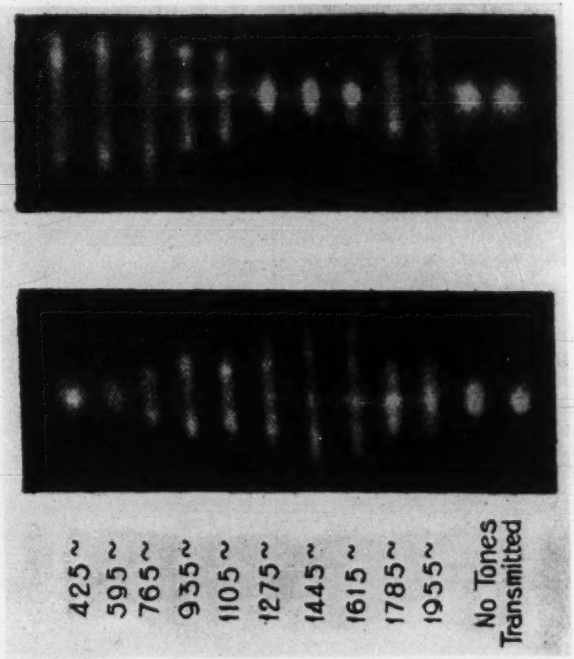
"Gear-wheel" frequency comparison, ratio 10 : 1.

higher frequency is an exact multiple of the lower. If the frequency ratio is not a rational number the gear-wheel rotates showing the amount of the lack of synchronization.

Two interesting applications to the study of radio telephony are illustrated in Figs. 35 and 36. Figure 35 shows two characteristics of a transatlantic radio channel, the tube plotting the amplitude of the received signal at a number of modulating frequencies. In Fig. 36 are plotted the magnitude and direction of static crashes as they were shown on the screen of the oscillograph tube.

For demonstration purposes the tube may be used to determine the value of the ratio of charge to mass of the electron, designated by e/m. The classical method is obvious from the derivation of the sensitivity of the tube given above.

FIG. 35.



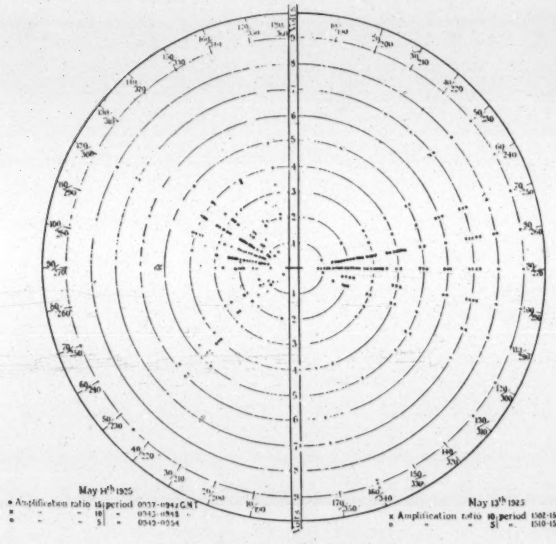
Transmission characteristic of transatlantic short-wave radio channel.[26]

[26] Potter, R. K., *Inst. Radio Eng.*, 18, p. 581, 1930.

Especially is this so if we can assume the two fundamental relations $1/2\ mv^2 = eV$; $mv = eHR$. The method is subject to some error because the extent of the deflecting fields cannot be exactly determined, and because of the space charges in the tube.

A more accurate method of arriving at the value of e/m is

FIG. 36.



Azimuthal distribution of atmospherics.[27]

due to H. Busch.[28] A long solenoid carrying constant current creates a uniform magnetic field in the tube parallel to its axis. The electrons travel in spirals in this field in such a way that when the field has one of a series of values the electrons are focused on the screen. These critical values of the mag-

[27] Watson, Watt and Herd, *Jl. I. E. E.*, **64**, p. 611, 1926.

[28] Bush, H., *Phys. Zeits.*, **23**, p. 438, 1922.

netic field are given by the equation

$$H = \frac{2\pi n}{L}\sqrt{\frac{2m}{e}}\,V;$$

where $n = 1, 2, 3, \ldots$ etc., L is the length of the beam and V the driving potential. In this method there is less disturbance from gas focusing and space charge if the filament current is made as low as will give a still visible spot with the magnetic focusing.

From the beginning the cathode ray oscillograph was recognized as a tool of great promise. Its use was limited, however, by the difficulties of maintaining a constant degree of vacuum and of providing a suitable source of high voltage, as well as by the general bulk and clumsiness of the apparatus. We have seen that in the nearly thirty-five years since the first invention of the tube, many improvements have been made both in the structure of the tube and in the methods of operation so that the handicaps under which the early apparatus was used have been very largely eliminated. The introduction of the low voltage, high sensitivity tube of moderate cost expanded the use of cathode ray oscillographs rapidly, until now they are used in almost every laboratory where high frequency measurements are made. In the plants of the Bell System alone more than a hundred of these instruments are in constant use for research, for the supervision of speech transmission channels, and for the control and calibration of manufactured products. Originally an intractable and little used device, the cathode ray oscillograph has become an almost universal scientific and industrial tool.

Physical Constants of Krypton and Xenon. F. J. ALLEN AND R. B. MOORE of Purdue University (*J. Am. Chem. Soc.*, 1931, *53*, 2522–2527) have determined the physical constants of these rare gases with the following results:—

Krypton. Density 3.733 ± 0.007 grams per liter, atomic weight 83.6 ± 0.2, boiling point −152.9 ± 0.3° C., triple point −156.6 ± 0.1° C. at 557 ± 3 mm.

Xenon. Density 5.887 ± 0.009 grams per liter, atomic weight 131.4 ± 0.3, boiling point −107.1 ± 0.3° C., triple point −111.5 ± 0.5° C. at 600 ± 20 mm.

J. S. H.

Occurrence of Vitamin A in Corn. G. S. FRAPS (Texas Agric. Exp. Sta. Bull., 422, 46 pages, 1931) has studied the occurrence of fat-soluble vitamin A in different varieties of corn, using the biological test with rats as the experimental animals. Yellow corn was rich in this vitamin, variegated and red varieties occupied an intermediate position, and white corn was very poor in the vitamin. The vitamin content of crosses of white and yellow corn was governed by genetic factors. Yellow corn meal was also rich in vitamin A. The vitamin content varied in the crops of three successive years.

J. S. H.

Proximate Composition of Fresh Vegetables. CHARLOTTE CHATFIELD AND GEORGIAN ADAMS of the Bureau of Home Economics, U. S. Department of Agriculture, have collected data on the chemical composition and caloric value of approximately 100 fresh vegetables (U. S. Dep. Agric. Circular No. 146, 24 pages, 1931). Data on many recently introduced vegetables are included, e.g. chinese cabbage, broccoli, dasheen, and udo.

J. S. H.

Detection of Acetone. S. IRA WILBUR (*Chem. Analyst*, 1931, *20*, No. 4, 11) recommends the ring test for the detection of the presence of acetone in alcohol. The alcohol is diluted to approximately 10 per cent. by volume; 0.5 gram of ammonium sulphate is shaken with 5 cc. of the diluted alcohol until solution is complete; 3 drops of 10 per cent. solution of sodium nitroprusside in water are added and mixed by shaking; then concentrated ammonia water is stratified over the reaction mixture. At the end of 5 minutes, a violet ring forms at the junction of the two liquids if 1 drop or more of acetone be present in 100 cc. of the original alcohol.

J. S. H.

REPORT ON THE WORK OF THE BARTOL RESEARCH FOUNDATION, 1930–1931.*

MADE TO THE MEMBERSHIP OF THE FRANKLIN INSTITUTE

BY

W. F. G. SWANN, D.Sc., Director.

INTRODUCTION.

In former reports which I have made in the form of lectures to the Institute upon the work of the Bartol Research Foundation, I have endeavored to summarize all of the problems and investigations under way at the time. As the work of the Foundation has grown, the difficulty of doing this in the short space of an hour has become increasingly great. The lectures and the faces of my audience have become longer and longer, so that I have decided to change my plan and present this evening only a few typical examples of the work in progress, leaving to the printed report a more detailed statement of the work as a whole.[1]

I always find it necessary to commence these lectures with a sort of overture, in which preparation for what is to come is made by playing little samples at the beginning. I must remind you once more that the atom consists of a central nucleus which contains practically the whole of the matter of the atom, all of the positive charge and some of the negative charge. Then outside of this nucleus there exists in the form of electrons an amount of negative charge equal and opposite to the net positive charge which resides in the nucleus. It is the nucleus which characterizes the atom, and a change in the nucleus changes the atom. A great deal of effort has been expended within the last twenty years in seeking to understand the activities of the external electrons. It is in the activities of these electrons that we seek the explanation of the emission of light by an atom; of the chemical action of the atom; of the

* Presented at the Stated Meeting held on April 15, 1931.

[1] The report here printed is so amplified.

emission of X-rays by the atom when suitably stimulated, and indeed of all of those activities exhibited by the atom which are in any way controllable by man. The way in which we have endeavored to understand these matters has varied. The ambition of the physicist of the Victorian era was to see the workings of all things unseen in the image of the workings of the things which could be seen. Even as a man has sought to visualize the Creator in his own image, so he has sought to visualize the workings of the unseen agencies of nature in the images of the things he finds around him. He would like to see the atom work in the same way that a dynamo works or the ripples on a bowl of water, something which has become familiar to him; and he will cling to such a model for a long time. He will cherish it as a haven of safety in his thinking, and he will shut the eyes of his mind and imagine that he holds it long after it has in reality evaporated. The late Victorian models of the atom, crude as they were, endeavored to see the atom's light as originating in vibration of its electrons according to the recognized laws of classical electrodynamics. Then came the Bohr theory in which the atom was pictured as a sort of solar system with a nucleus at the center and with external electrons revolving around it as planets revolve around the sun. In order to emit light, an atom had to be excited—that is to say, one of its electrons had to be thrown into an outer orbit in such manner as we might imagine the earth to be thrown from its present orbit into the orbit of Neptune. Then, in falling back to its original orbit, it was supposed that light was emitted, and on this basis it was possible to work out a correlation of the theory and facts with a degree of completeness which was extraordinary indeed. Many of us have probably felt that in spite of the rather artificial assumptions associated with the Bohr theory, we still had a model of the atom. Yet think how far we really were from such a model. The only model of the atom we had was a model of the part which did not do anything. The electrons, while rotating in their orbits, were supposed to be completely devoid of any means of making themselves evident to the external world. It was only during the process of passing from one orbit to another that the radiation, the visible symbol of connection between the seen and the unseen, became evident, and

the mechanism of this procedure was left wholly in the dark. One who thinks he has a model in the Bohr atom, because what he draws for the atom on paper looks somewhat like the solar system, is in the position of one who deludes himself in a manner which I may illustrate as follows:

Suppose I should see a strange new being, a giant, and exclaim, "See what huge muscles he has. Such a man should be able to swing a hundred-pound hammer with ease. See what large eyes he has. Such a man should gather enough light from the skies to see stars invisible in our most powerful telescopes. See how far apart his eyes are. Such a man should have stereoscopic vision which would enable him to see depths in mountains hundreds of miles away," and so on. And then suppose, when we came to investigate this creature, we found the weights which he did lift had no relation whatever to the size of his muscles, but depended in a rather peculiar way upon the length of his hair and the color of his eyeballs. Suppose that his powers of vision were no greater than ours, and such as they were were determined by the difference between the lengths of his toes and the diameter of his ears. And suppose that, far from having stereoscopic vision so superior to ours, he could not see depth in anything at all. Nobody can deny me such satisfaction as I might get by continuing to think of this monstrosity as a man, but I think I should have to admit that he was a very peculiar kind of a being, a being so different from other men that it would be very unsafe to utilize my experience of such men to come to a conclusion as to what he would be likely to do. Such experience of him as I might develop would have to be founded entirely upon his own actions. In the sense that this strange being represents to us the model of a man, the old Bohr theory may be said to represent a model of an atom. But after all, it is the properties of the thing that we study which count. It is of these that we make use. The great thing is to get our minds going in the matter of thinking about these things; and for some peculiar reason inherent in the psychology of mankind we think much better if we have a model than if we have not. I may even go farther and say that we think much better if we think we have a model, even though we have not. The valuable work of stimulation to think about the things

of nature gets largely done before we come to the terrible realization of the fact that we may not, in our mental process, have utilized at all any of the features of our supposed model. This model is a deceitful thing, but it is well gowned and adorns well the drawing rooms of our brain, provided we do not listen too much to its philosophy.

The Bohr theory has been superseded by other theories of atomic structure which are more artificial in their apparent form, but which are more acceptable to our imagination than they would have been fifty years ago, because of the disciplining process to which our minds have been subjected in the gradual transition from the crude mechanical models of mid-Victorian days through the capricious model of the Bohr theory to the present time. However, most of the models, attempts at models, and mathematical paraphernalia which have discarded models, have had to do with the outer structure of the atom, that which lies outside of the nucleus. The mathematician always likes to be able to say as much as possible without knowing what he is talking about, and so the entities of nature which permit him to talk of them in this way are particularly agreeable to him. Most of the properties of the nucleus, so far as they concern the external structure of the atom, are expressible in a manner which has very little relation to any internal structure, mechanical or otherwise, of the nucleus itself.

IMPORTANCE OF INVESTIGATIONS CONCERNING THE NUCLEUS.

While attention was concentrated upon the features of the outer structure of the atom, there was less activity in the matter of trying to do a similar thing for the nucleus. And yet, in a sense, the nucleus is the most mysterious part of the atom: it is the thing which differentiates one atom from another. It is the volcano of the atom, a thing which seldom affects the external world but when it does, affects it with violence and with the accompaniment of what, from the standpoint of the particular atom concerned, is a far greater catastrophe than any earthly volcanic eruption.

Certain things about the nucleus we know quite definitely. We know that if the elements be arranged in a row in increasing order of their atomic weight, then the nuclear charge in-

creases by one unit (the charge on a proton) from any one element to the next higher. We may, however, have several atoms which have the same charge but different masses, because we may add protons and electrons to the nucleus in pairs without altering its charge but with very definite alteration of mass. Atoms which differ in mass but not in nuclear charge are called isotopes of each other.

It is of interest to consider a few of the phenomena into which the properties of the nucleus enter. In the radioactive elements, such as radium, we have a state of affairs where the nucleus is in an unstable condition and explodes occasionally with the emission of one or all of three kinds of radiation: the alpha particle, which is a positively charged atom of helium traveling with a velocity of about 12,000 miles per second; the beta ray, which is an ordinary electron traveling with a velocity comparable with that of light, i.e., 186,000 miles per second, and the gamma ray, which is a very hard X-ray traveling with the velocity of light. Radium has a very complicated nucleus. When the alpha ray, beta ray, and gamma ray depart, there is still a good deal left, and that which is left constitutes the nucleus of a different kind of an atom, radium emanation. This radium emanation in time undergoes a transformation and gives birth to another substance, radium "*A*," and so on. One of the most fundamental problems in atomic structure would be solved if we could ascertain just what it is that determines the relative stability of the nuclei of the different atoms. Why, for example, does an atom of radium live, on the average, for 2,500 years before breaking up, while an atom of radium "*A*" lives, on the average, only about four minutes, and an atom of uranium lives for about 6.6×10^9 years. It becomes of interest to inquire whether all of the elements may break up spontaneously in this way, even though the rate may be slow, so slow that it would not be observable in our laboratory experiments. Already science has given us a large amount of information upon these matters. As I have already implied, we have reason to believe that all of the atoms are built up out of protons and electrons, and the evidence shows that the weights of the different atoms are very nearly multiples of the weight of a proton plus an electron. However, they are not quite exactly multiples of this

quantity. Now, we have come to learn that if a proton and an electron be brought into each other's vicinity, the mass of the pair, as measured by its weight, for example, is no longer the sum of the masses of the individual proton and electron when measured separately. There is, in fact, a loss of mass which is greater the nearer the proximity of the electron to the proton. Moreover, modern physics has taught us that mass and energy are, in a large sense, equivalent, so that if mass disappears in this way energy is evolved, frequently in the form of radiation. Thus, when we consider the nuclei of a group of atoms as assemblages of protons and electrons, the rearrangement of those protons and electrons into other aggregates, so as to form other atoms, is not a matter which may be thought of simply as a mere transference of those protons and electrons. Thus, for example, so far as numbers of protons and electrons are concerned, I can, in imagination, take a gram of helium, each atom of which consists of four protons and four electrons, and convert it into a gram of hydrogen, each atom of which contains one proton and one electron. However, the electrons and protons in the helium nucleus are packed together tightly, and on this account a certain amount of their mass had been lost with its equivalent amount of energy, so that I should have to supply energy to those protons and electrons of the helium atom in order to persuade them to form hydrogen even if I could persuade them then. To convert one gram of helium into hydrogen would require a supply of energy which would be sufficient to raise one and one-half million kilograms of water from the temperature of melting ice to the boiling point, although this amount of energy would correspond to a mass of only about 0.007 of a gram.

Knowledge of the relative masses of the different isotopes of the atoms provides us with information as to the energy changes which it is necessary to invoke in order that transformations from one atom to another may be considered. A large amount of work of this kind has already been done, notably by Dr. Aston of Cambridge University, England, and by Dr. Dempster of Chicago. As will be realized from the examples I have already cited, the amounts of energy associated with relatively small-mass differences are enormous, so

that measurements of the isotopic masses must be made with great accuracy in order that we may predict with certainty, from their differences, the magnitudes of the energy transformation changes involved in passage from one atom to another.

The elements are not quite pure substances in the sense in which that term was formerly understood by the chemist. They are usually mixtures of different isotopes having, of course, slightly different weights. The relative amounts of these isotopes present in any element, the relative abundance, as it is called, of the isotopes, is the quantity which plays an important part in discussing the stability of the isotopes and the processes which enter to determine that stability.

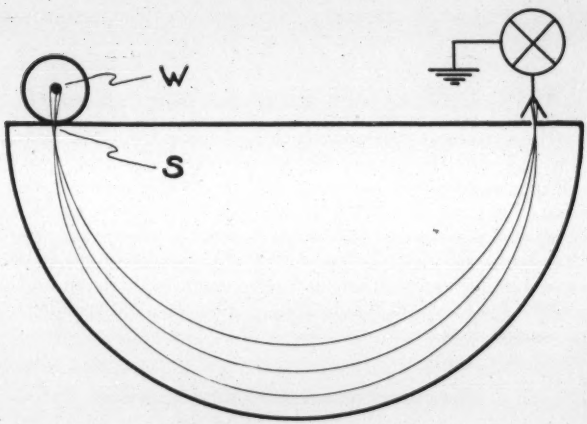
Then there are other considerations of vital importance. When the chemist determines the atomic weight of an element, we must think of that atomic weight as being contributed to by the various isotopes of which the element is made up, and if we measure the masses of these individual isotopes, and the relative numbers of each, we ought to be able to reconstruct, from the data so obtained, the atomic weights which the chemist has given us. If the agreement is good, then that is the end of the matter, but if it is not, then we have to seek some further explanation, and the search leads us on and on to new aspects of the whole story. The physicist spends most of his life looking for trouble. That is how he makes discoveries.

EXPERIMENTS ON ISOTOPES OF THE ELEMENTS.

It is on such investigations as I have hinted at in the foregoing that Dr. Bainbridge is engaged. One of his problems has been a determination of the abundance of isotopes of different atomic weights in certain elements. Let me first describe the general procedure. A salt containing the element under investigation is heated on a wire W through which an electric current is passed. (See Fig. 1.) Under these conditions a large number of the atoms lose electrons and become positively charged ions. These ions are subjected to a definite difference of potential, so that they attain a high velocity with which they pass through a slit S in the apparatus into a magnetic field whose direction is perpendicular to their line of

flight. The stream of charged particles coming through the slit is slightly divergent, because all of the particles do not travel in the same direction; but, as is well known, the magnetic field causes them to converge to a focus at the opposite end of the diameter of the path which they describe. The diameter of their path and the position at which they come to a focus depend upon their velocity, the magnetic field, and the mass of the particles. The kinetic energy which they receive is determined by the potential difference through which

FIG. 1.



they are accelerated towards the initial slit. Thus from a knowledge of the magnetic field, path diameter, and potential difference referred to, it is possible to determine the mass of an isotope. Instead of allowing the different isotopes to come to a focus at different places, it is possible to vary the accelerating potential differences so as to cause them all successively to come to the same spot. It is also possible to make that spot a slit through which the ions enter a chamber which is connected with an electrical measuring instrument in such a manner as to measure the charge acquired. Under these conditions, measurements of the amount of charge obtained

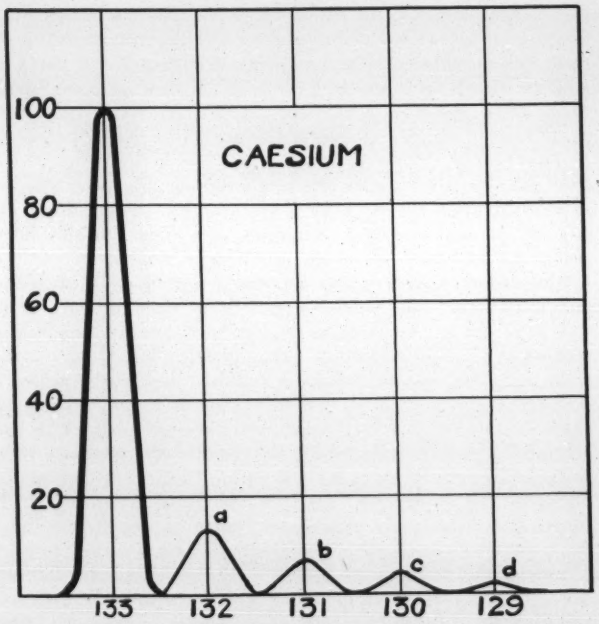
from the different isotopes gives a measurement of the abundance of the different isotopes in the elements concerned.

As an example of the experiments bearing upon the foregoing considerations, I will first cite an investgation by Dr. Bainbridge[2] upon the isotopes of cæsium. The atomic weight of cæsium would be 134.024 if all of the protons and electrons in its nucleus retained the same mass as they have in the hydrogen atom. However, we would not expect to realize this atomic weight by the ordinary chemical measurements, because we know that when protons and electrons combine to form helium there is a loss of mass mounting to 73 parts in 10,000. If the protons and electrons in cæsium were made up, so far as possible, in helium groups, which would leave one proton over, we should expect the atomic weight of cæsium to be 133.064 However, even when the helium atoms are combined in other nuclei, there is a further change of energy depending upon the packing of those units. From a knowledge of the packing effect which has, as a matter of fact, been measured in elements which are closely related to cæsium in the atomic weight scale, we would anticipate a probable packing effect which would permit us to think of an atomic weight of 132.93 for cæsium, provided, of course, that it was composed of a single isotope. On the other hand, the chemically measured atomic weight is 132.81. It then becomes of interest to inquire as to whether the discrepancy between these two numbers is to be accounted for by an error in the chemically determined atomic weight, by the presence of a suitable amount of an extra isotope in cæsium, or by an abnormally large packing effect in the cæsium atom which causes it to diverge in this respect from its neighbors. The chemically measured atomic weight is sufficiently near to that of one of the isotopes to enable us to know which of those isotopes, if there be more than one, is present in greatest abundance, and this isotope is the one with a mass of 133 on the usual scale. It is possible to think of isotopes of weights 132, 131, etc., and to fit up the chemically measured atomic weight in various ways out of these. On the other hand, by analogy with other elements whose atomic weights lie between

[2] The complete account of this investigation appeared in the *Physical Review*, 36, 1668, 1930.

nitrogen and lead, we do not expect to find more than two isotopes in cæsium. For this reason, Dr. Bainbridge has calculated the amount of each of the isotopes 132, 131 down to 129 which would have to be present in order to make the chemically measured atomic weight agree with the expected value. In Fig. 2 the horizontal axis represents the mass

FIG. 2.



number and the vertical axis the current expected, in a typical case, when the accelerating voltage is adjusted so that isotopes of the corresponding mass number are caused to enter the slit of the electrical measuring instrument. If the conditions were ideally simple, each of these curves would be a vertical straight line, whose height represented the total current for

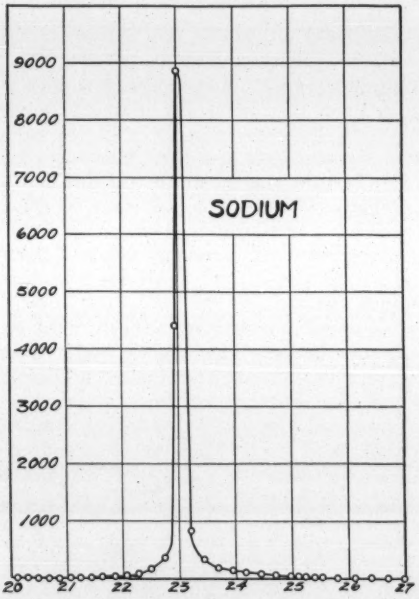
that isotope. In practice, on account of the finite width of the slits and other subsidiary considerations, it is the area of the curve associated with the isotope, which represents the abundance of that isotope present. On this basis, the curves, *a*, *b*, *c*, and *d*, represent what would be expected as regards the distribution of isotopes on the assumption that in addition to the main isotope, 133, there were present 132 in the case *a*, 131 in the case *b*, and so forth. The experiments show conclusively that there is less than 1/10 of the amount which would be calculated for any of the isotopes as necessary to combine with the main isotopes to produce the chemically measured atomic weight. We are thus left with the alternative of an error in the chemically measured atomic weight, or an abnormally large packing effect for the cæsium atom.[3] This kind of experiment is of a particularly fortunate nature, because there is hardly any way in which it can indicate an erroneous result. We can imagine ways in which currents can be obtained in our instruments when they ought not to be present, but there is hardly any way in which the isotope can fail to make itself felt in Dr. Bainbridge's experiment if it should actually exist.

Several elements which had formerly been supposed to contain only one isotope, have, in the light of more recent measurements, revealed a slight amount of additional isotopes. In particular, for example, carbon, which was formerly thought to have only one isotope of atomic weight 12, is now known to have about one part in 2,500 of carbon 13. Oxygen, which figures so fundamentally as a standard in atomic weight measurements, was formerly thought to have a single isotope of atomic weight 16 but is now known to have very small amounts of isotopes 17 and 18 respectively. Nitrogen, formerly thought to have one isotope of weight 14, is now known to have a slight amount of 15. Beryllium, whose main isotope was Be 9, is now known to have a small amount of Be 8. One of the atoms which has been regarded as having but one isotope is sodium, and with the degree of sensitivity attainable in Dr. Bainbridge's apparatus it seemed worth

[3] Recently, Dr. F. W. Aston (*Nature*, 127, 813, 1931), has determined the packing fraction of cæsium. A figure of 05.0 2.0 was obtained, giving a value 132.91 0.02 for the atomic weight of cæsium.

while to see to what extent this conclusion was justified. The curve in Fig. 3 again represents, by the vertical ordinates, the currents to the electrical measuring system plotted against the atomic weights of the isotopes. It will be seen that there is one isotope of atomic weight 23, and that is all. Dr. Bainbridge is able, in fact, to conclude from these measurements

FIG. 3.



that any other isotope which may be present, is present in extremely small amounts. Thus, for example, if isotopes 21 or 25 are present it is necessary to assume that they are present to an extent less than one part in three thousand of the main isotope, in order to fit in with Dr. Bainbridge's data.[4]

[4] For details of this investigation see JOURNAL OF THE FRANKLIN INSTITUTE, 212, 336, 1931.

Another problem of significance connected with isotope measurements concerns the relative abundance of the isotopes in certain elements as a function of the temperature. To expect that there would be any relationship between the number of isotopes in an element and the temperature would be somewhat like expecting the behavior of an ocean liner's engines to be affected by the noise of the people chattering on the deck. However, certain investigators have reported an effect of temperature upon the relative abundance of the isotopes in lithium, an effect which corresponded to a change in the relative abundance of two isotopes from 12 to 1 to 120 to 1 for a change of temperature of about 100 degrees. In view of the great importance of this matter and of the very drastic bearing it would have upon our notions of the relation between temperature and nuclear constitution, if it were true, Dr. Bainbridge has repeated the experiment under the improved conditions afforded by his equipment. He finds that, at a temperature of about 1270° K the relative abundance of lithium 7 to lithium 6 was represented by the value 10.75, to an accuracy of about 8 per cent. At a temperature about 100° higher than this, a corresponding ratio of 11.31 with an accuracy of better than 1 per cent. A temperature 310° higher gave a ratio of 11.5, so that over these ranges of temperature there is certainly not as much as 10 per cent. change in the ratio of the abundance of the two isotopes, and in all probability the agreement is better than this.[5] This conclusion reached by Dr. Bainbridge is a very comforting one; because, had it been otherwise, such drastic modification in our notion of the relation between the temperature and nuclear constitution would have been necessary as to endanger the structure of everything else which we had made up in our minds concerning these matters. I suppose that we ought to welcome a revolution of this kind, on the basis that the greater the catastrophe the greater the opportunities for new experiences. However, we do not relish this kind of thing in matters political, and even physicists are, after all, somewhat human in certain things. While Dr. Bainbridge's results in relation to temperature are of the negative rather than of the positive

[5] Dr. Bainbridge has fully described his work in the JOURNAL OF THE FRANKLIN INSTITUTE, 212, 317, 1931.

type and, therefore, are less of a spectacular nature, this very circumstance carries with it the greater guarantee of their truth than would have been permissible had a positive been found. For the number of ways in which it is possible to get an effect when there is none is very large compared with the number of ways in which it is possible to fail to get an effect when there is one. Thus, in comparison of Dr. Bainbridge's results with those of other investigators, quite apart from all questions of experimental skill, the laws of chance naturally favor the null results.

Then Dr. Bainbridge has started a search for isotopes of the element uranium. This problem has a special significance in relation to the origin of the element protoactinium and the actinium radioactive series. The natural parent of actinium is an element called protoactinium, but there are difficulties concerned with the amount of this element necessary to account for the actinium actually known to exist, and the difficulty would be eliminated were it possible to find a source of protoactinium. A theoretically possible source is one of the isotopes of uranium, hence the importance of a search for such an isotope.

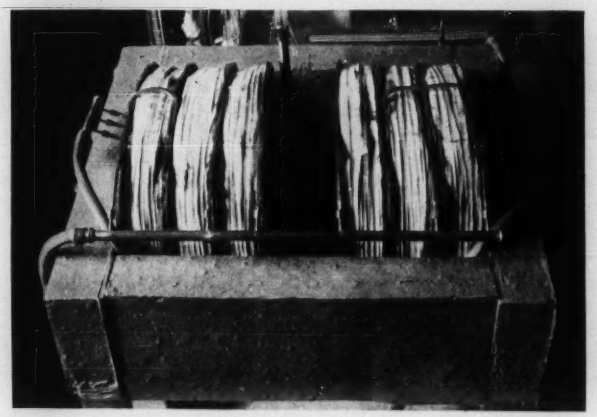
Another aspect of the importance of determining the relative abundance of different isotopes in the elements, and in particular of seeking for isotopes of uranium, may be illustrated by a case particularly applicable to the determination of the age of the earth or rather of the period which has elapsed since certain rocks were formed. This is a problem which is of peculiar interest to the geologist, and a group of geophysicists interested in the age of the earth have been particularly anxious through their representative, Dr. Arthur L. Day, the director of the Geophysical Laboratory in Washington, and a valued member of the Board of the Bartol Foundation, in having Dr. Bainbridge determine certain isotopic ratios which have an important bearing upon this problem. The situation is this: It is known that uranium in radioactive disintegration gives rise finally to lead; and if we assume that when the rocks containing the uranium were formed no lead was present, and if we know the rate at which the uranium and the successive products of disintegration down to lead decay, it is possible to calculate the time which has elapsed

since the lead started to form until the present time when the lead is present. However, two matters of uncertainty present themselves. In the first place, there is ordinarily, mixed with the uranium, lead which has not come as the offspring of that element. This lead is distinguished from the uranium lead having a slightly different atomic weight, an atomic weight of 207.2 and it is made up of lead isotopes 206, 207, 208, occurring in a constant ratio relative to each other, as compared with the atomic weight 206 which would be obtained from the uranium. It is impossible to separate the two kinds of lead by chemical means and so, by this means, to ascertain how much of each is present. If, however, the apparatus for analyzing isotopes is sufficiently sensitive to be able to detect the difference between 207 and 206, then we can readily determine the relative amounts of each of these isotopes present and, as a matter of fact, the relative amounts of uranium lead and ordinary lead. In this way we would be able to make a more accurate estimate of the age of the rocks. Then another consideration enters. It is not certain that the starting point in the origin of the lead is a single isotope of uranium. More than one isotope may be involved, and each of these isotopes may have a different decay period. There may be also more than one isotope in the lead which results. A proper calculation of the age of the rocks from a knowledge of the relative amount of uranium and uranium lead finally present would have to take into account the separate rates of decay of each of the individual isotopes and their successive products together with the relative abundance of all of the isotopes of the lead and uranium. The decay constant as formerly measured for the uranium in bulk is simply a crude approximation whose use might lead to considerable error in the evaluation of the age of the rocks in cases where the amount of lead which had been formed from the uranium was appreciable compared with the amount of uranium itself. Dr. Bainbridge will be supplied by Dr. Day with the uranium obtained from the rocks in question, and he hopes with his apparatus to be able to determine the relative amounts of the isotopes of the uranium present if there be more than one isotope and the relative amount of the lead isotopes associated with them.

I have already referred to the importance of an accurate determination of the atomic weights of the isotopes in order to determine what is called the packing fraction, that is to say, the quantities which are associated with the losses of mass determined by the electrons and protons coming together in the nuclei; and the measurement of these packing fractions is another of Dr. Bainbridge's proposed investigations.

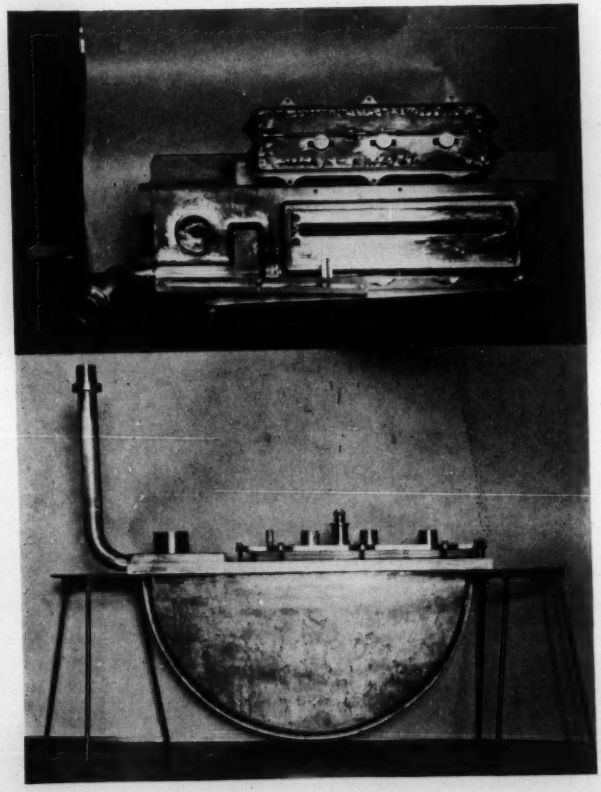
Figure 4 is a picture of the electromagnet in which the isotopes are bent into their circles. Figure 5 is a picture of

FIG. 4.



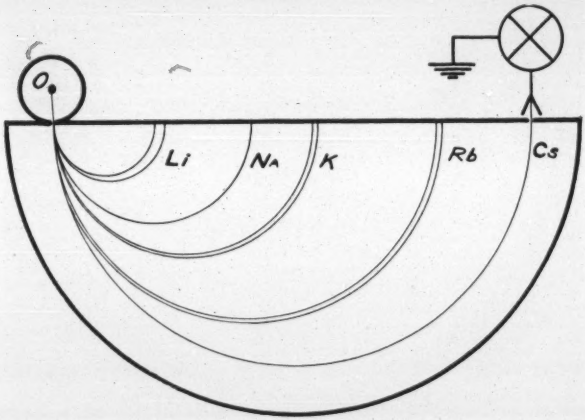
the chamber in which the isotopes are made to describe their circular paths. It must, of course, be evacuated to a high degree. In this particular apparatus the situation is as represented diagrammatically in Fig. 6. A potential difference between the filament and the cylinder serves to draw off the positive ions and cause them to pass through the hole at *O*. These circles represent, pictorially, the paths described by the different charged particles. As I have already stated, it is possible to bring all of them successively to the same point by altering the difference of potential under which the positive ions are accelerated.

FIG. 5.



With the above apparatus one is limited to those ions which can be obtained from substances in the form of wires, or to substances which can be deposited on wires, because for the required high resolving power it is necessary that all of the ions shall have fallen through the same difference of potential before passing into the chamber where their circular paths are described. In Dr. Bainbridge's later apparatus, designed for more accurate measurements of the atomic weights of the isotopes, and for the measurement of the relative abundance of the isotopes, a somewhat different scheme has been employed.

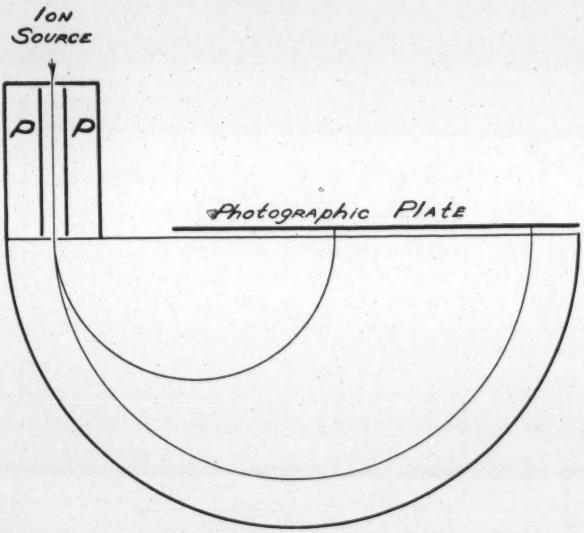
FIG. 6.



The plan has been to use what is called a velocity filter. The ions are produced in the region indicated in Fig. 7, and have received their velocity under some influence which I need not describe in detail. P. P. represents a pair of parallel plates between which is produced an electric field whose direction runs perpendicular to the magnetic field. A positive ion passing between these plates would be bent from right to left by the influence of the electric field, and if the direction of the magnetic field is right they will tend to bend in the opposite direction as a result of the magnetic field. By proper adjust-

ment of the electric field to an amount depending on the velocity of the ion, it is possible to insure that the ion paths do not bend at all and consequently pass accurately through the two slits at the two ends of the device. The arrangement insures that for fixed electric and magnetic fields only one velocity of ion will succeed in passing through both slits. If the velocity is wrong the ion will be turned off to the side and prevented from getting through the second slit. This device not only secures a more uniform velocity for the ions in general but enables one to work with ions which are not initially uniform in velocity. The selector picks out from the heterogeneous velocity group a single velocity only. In this modified form of apparatus the plan is to use a photographic means of recording the isotopes and make no attempt to bring them all to the same spot, as was done in the case of the electrical

FIG. 7.



recording. The relative abundance can then be determined from the density of the photographic record. I may remark, incidentally, that in order that the results may be properly interpretable it is helpful to investigate the relation between the velocity of positive ions and their efficiency in producing photographic effect. Such an investigation has been carried out by Dr. Bainbridge.

EXPERIMENTS ON THE REFLECTION OF ATOMS FROM CRYSTALS.

Last year I reported experiments by Dr. Johnson on the reflection of hydrogen atoms from crystals. You will recall that the interest of the experiment lies in the fact that the latest atomic theories lead us to expect that a beam of atoms possesses the same wave-like properties as those which have long been known to characterize the propagation of light and sound.

According to the older views an atom was regarded as a bullet-like corpuscle. Because of the roughness of a crystal surface, inherent in its atomic constitution, a beam of such corpuscles should be reflected in perfectly random directions. On the other hand, if we regard the atom as a beam of wave radiation, we should expect an entirely different character of reflection which may be best described by citing the analogous optical experiments.

When a beam of light falls upon a regularly spaced array of scattering centers, such as a grating of fine wire or a set of regularly spaced reflecting points, one beam is reflected at an angle equal to the angle of incidence, and in addition a number of other beams leave the crystal in directions determined by the ratio of the spacing of the grating to the wave-length of the light. These extra beams are known as diffraction beams, and it was their discovery by Thomas Young early in the nineteenth century which resulted in the universal acceptance of the wave-theory of light. Likewise, the discovery of diffraction was regarded as proof sufficient of the wave-like character of both X-rays and electrons. Besides being wave-like, it is also well known from the requirements of experimental facts that we must associate bullet-like properties with these waves, and both experiment and the modern wave-mechanics theory lead to a relation connecting the velocity of

the bullet-like electrons with the wave-length of the wave-like radiation to which they correspond. It is, of course, a confusion of terms to regard an electron or a proton (the light corpuscle), as being both a corpuscle and, at the same time, a wave, but we have a correct view of the situation if we think of the wave as a sort of a guiding field which controls the motion of the corpuscles. Upon striking the crystal, the wave becomes split up into different reflected beams, as light waves, for example, are split up by a grating. The corpuscle is then thought to follow the directions taken by the beams of waves as though guided in some way by them. At the crystal a decision has to be made by the corpuscle as to which of the various wave beams it is to follow, some deciding upon one beam and others, upon other beams, so that in the end each of the wave beams is represented by its proportion of the corpuscles.

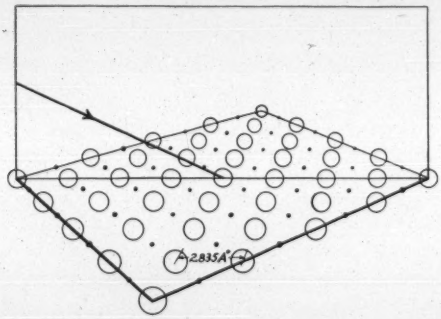
At the time Dr. Johnson started this work, it was known that some such view as has just been described had to be taken to explain the behavior of electrons and photons, but in the case of the atom only the corpuscular properties were known. Whereas the theory suggested that atoms might also have wave-like properties, the atom was so distinctly a corpuscle in all of the many characteristics which were known that it seemed exceptionally significant to be able to prove experimentally that it, too, was wave-like.

At times during the course of his experiments, the difficulties in obtaining a definite answer seemed great, but Dr. Johnson finally succeeded in eliminating troubles until finally the demonstration was complete that hydrogen atoms when reflected from lithium fluoride crystals behaved as though the atom as a whole was associated with the same wave-like properties as the electron or the proton.

Although I have described these reflection patterns in some detail in my last year's report, it seems worth while to review them again in the light of the more complete experimental results which are now at hand. Let us suppose that Fig. 8 represents the surface of the lithium fluoride crystal, the circles representing the fluorine atoms and the dots, the lithium atoms. The crystal thus provided an array of regularly spaced scattering centers so that when a beam of hydrogen

atoms was allowed to fall upon it, the reflected atoms followed such directions as to produce, on a sensitive plate, a pattern characteristic of the array and of the wave-length of the atom beam. First let me show you the patterns which would be expected theoretically on the basis that the atom acted like a beam of waves of the expected wave-lengths. Figure 9, *A* represents the case where the beam is incident at an angle of 45° with the plane of the crystal and in a plane perpendicular to one of the sets of rows of similar atoms. Figure 9, *B* corresponds to 45° incidence in a plane at 45° with the rows

FIG. 8.

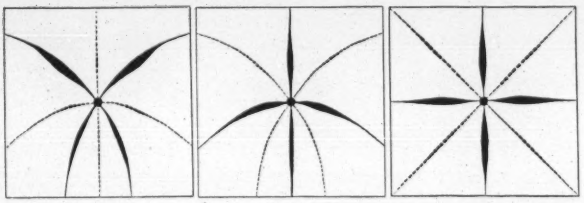


The arrangement of the atoms on the surface of an LiF crystal with respect to a beam incident in the 100 azimuth.

of similar atoms, and Fig. 9, *C* represents the pattern to be expected at normal incidence. In each case, the full lines represent what is called the "first-order" spectrum, that is to say, the pattern for which the reflected beams make the least angle with the reflected beam. The dotted lines represent the positions of the expected second-order spectrum. If all of the atoms had the same velocity, these lines would have appeared as dots, but since each atomic velocity corresponds to a separate wave-length, and since the incident beam contained atoms of various velocities, the patterns should be spread out in the manner indicated. The situation is analogous to what we should have in the case of light reflected from

a grating if the light were not monochromatic but contained a range of colors. Each color of light or velocity of atom produces its own pattern in a slightly different place, and the thickening of the lines in Fig. 9 is intended to indicate the distribution of intensity on the recording plate as expected from the distribution of velocities known to occur in the original beam of atoms. In order to emphasize the similarity of the atom waves and the light waves, it is of interest to see the kind of optical pattern which one would expect from a suitably chosen grating of a kind corresponding to the crystal surface. Of course, the optical grating must be on a larger scale than

FIG. 9.



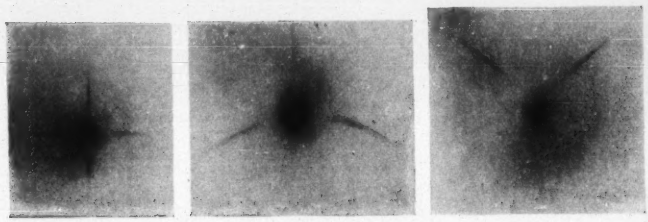
A *B* *C*

that of the crystal grating, for the wave-lengths associated with light, although very small, are much greater than those associated with the atoms. We can, in fact, duplicate the surface of the crystal for the optical experiment by using what is called a "cross-grating," which may be constructed of a piece of glass with a number of lines ruled parallel to each other in two sets, one set perpendicular to the other.[6] Figure 10, *A*, *B*, and *C*, represents the results actually obtained by Dr.

[6] Arranging such an optical grating exactly as the lithium fluoride surface was arranged in Dr. Johnson's experiments, but using a beam of light in place of the atomic beam, two patterns were shown in the verbal report. These revealed exactly the features sketched in Fig. 9 *A*, *B*, and *C*. It was seen that although the original light incident on the cross-grating was white, the patterns were colored, because at deflection the light rays of different color were reflected at slightly different angles. Thus a broadened-out color pattern was obtained instead of a pattern in white light. Corresponding to this separation of the light into colors, we expect the beams of atoms of different velocities to be reflected at different angles.

Johnson for the diffraction beams of atomic hydrogen, and it is seen that the patterns are of exactly the expected forms. The second-order beams are hardly visible except in the case of the normal incidence. This, of course, means that the intensity of the beam reflected from the second order is small compared with that reflected from the first order. Theory shows the pattern to be more spread out in the second order than in the first, and this spreading out is probably sufficient to account for the diminished intensity in the second order as compared with the first.

FIG. 10.



C B A

A. Diffraction of hydrogen atoms reflected at 45° in the 100 azimuth.
B. Diffraction of hydrogen atoms reflected at 45° incidence in the 110 azimuth.
C. Diffraction of hydrogen atoms reflected at normal incidence from an LiF crystal.

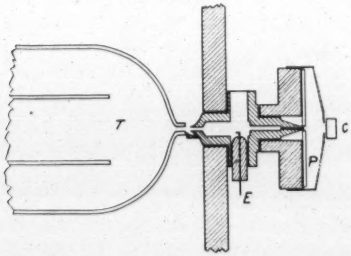
At the time of last year's report, Dr. Johnson had obtained patterns which, in the originals, could be seen to contain enough of these features to show that atoms were really wave-like, but the patterns were too faint when reproduced on the press to be entirely convincing. The recent work has provided an improvement of the technique, so that now even the printed results show the important features.

To complete the work on the proof of the wave-like properties of the atom as a whole, Dr. Johnson has made some quantitative measurements of the angle through which atoms of known velocities have been deflected, thus obtaining an experimental value for the wave-length. Inasmuch as the atom beam of necessity contained a range of velocities or wave-lengths, it might appear difficult at first sight to make a precise correlation between angular deflection and velocity.

The distribution, however, is characterized by the existence of one velocity, which may be calculated from the temperature, and for which there are more atoms than for any other. Corresponding to this velocity, the patterns show a maximum of intensity, and the angle at which this maximum appears is a measure of the wave-length of the atoms of that velocity. Quantitative measurements of this angle on several of the patterns have shown that the same relation exists between the velocity and wave-length of an atom as pertains in the case of electrons.

It would be tedious to describe all of the improvements which Dr. Johnson has made in his technique since last year.[7] Perhaps it will suffice to show what we may call the business end of the apparatus in its final form. It is a rather curious characteristic of physical technique that one starts off with a very big apparatus, and as the technique improves the apparatus usually gets smaller and smaller, each part having more and more meaning. The apparatus as used in the latest work is indicated in Figs. 11 and 12. Figure 11 represents the arrange-

FIG. 11.

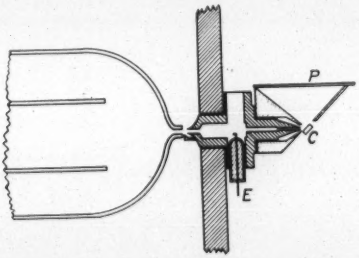


ment of slits, crystal and plate, for normal incidence. The gas from the atomic-hydrogen generator T passed through a fine hole, and then through a series of two very fine tubes on to a crystal C. The reflected atoms were received on a screen of molybdenum oxide P which was turned dark under the action of the hydrogen and displayed the patterns which were then

[7] The details are given in the *Physical Review*, 37, 847, 1931.

photographed in the usual way for reproduction. The wire E performed a very important function. The stream of hydrogen was always mixed with charged particles or ions, which had the undesirable property of destroying the reflecting power of the crystal. This wire could be charged so as to remove the ions before they got into the crystal chamber. Figure 12 shows the corresponding case where the crystal was mounted so that the beam struck it at an angle of 45°. This particular design secured the maximum degree of protection for the plate in the matter of contamination by impacts of atoms other than those which it was intended that it should receive.

FIG. 12.



The experiments described above have been concerned with a study of the wave-like properties of a beam of atoms. These properties having been established, it was then possible to use the atom beam in studying the atomic constitution of the crystal surface, and Dr. Johnson has already obtained important information concerning what is known as the secondary structure of the crystal in the case of lithium fluoride. For this purpose the atom beam has proven to be superior to any other type of wave radiation, for not only do the atoms have the short wave-lengths of very penetrating X-rays, but in addition they are completely lacking in penetrating power, so that the effects observed are entirely characteristic of the outermost surface layer of the crystal.

For several years it had been surmised that even the most perfect crystals were subdivided into minute blocks separated

by regions of lower density. In fact, such a structure provided the only way of accounting for the low breaking strength and for several other properties which could not be accounted for as characteristics of the primary crystal lattice. One might have thought that the existence of a secondary structure could have been determined by X-ray diffraction, but the volume of the low-density interstices proved to be too small to produce a detectable intensity in the X-ray pattern characteristic of this structure. The situation on the surface, however, is a little different, for there the secondary density variations can be developed by evaporation into grooves and ridges, and these constitute a secondary grating structure which produced on Dr. Johnson's plates a secondary spectrum of considerable intensity.[8] This secondary spectrum appeared as continuous bands, extending out from the specularly reflected beam in directions such as to show that the grooves on the surface were parallel to the lines along which the crystal breaks most easily. Thus a correlation was established between the low breaking strength and this spectrum. The secondary spectrum appears in Fig. 10 *B* as the blurred *X* structure of the specular beam which, without this spectrum, would have been exactly circular. At grazing incidence, this spectrum appears more spread-out, and Fig. 13 shows it for

FIG. 13.

the case where the incident beam was ribbon shaped and reflected from the crystal at 2° from grazing. Theoretical reasons have been given by F. Zwicky to indicate that the secondary grooves should be regularly spaced at a distance of about 70 A. in the most perfect crystal, but the stability of the structure is weak and irregularities could easily result from disturbances during the preparation of the crystal. The experiments lead to the conclusion that such irregularities

[8] This work has been published in full in the JOURNAL OF THE FRANKLIN INSTITUTE, 212, 507, 1931.

were present in the crystals studied, for a perfectly regular system of grooves at the expected distances should have produced a secondary spectrum having a minimum of intensity close to the specular beam, whereas the observed spectra do not show this characteristic.

EXPERIMENTS ON MEAN LIVES OF ATOMS ON EXCITED STATES.

Last year I reported upon certain work carried out by Dr. Maxwell upon the so-called mean lives of atoms in excited states. I fear that again I must spend a moment or two in saying some things about atomic structure necessary to make the significance of these investigations clear. It will suffice for our immediate purpose to think of the atom in a sense which is now a little obsolete, but which is convenient for purposes of description and which will not lead us into error as regards what I have to say. We think then of the atoms of ionized helium, for example, which is the gas Dr. Maxwell is working upon, as composed of a central positive nucleus with an electron revolving around it in an elliptic or circular orbit. According to the principle of the quantum theory of atomic structure, only certain orbits are possible, and light is emitted when the electron jumps from some outer orbit to an inner one. In each orbit the electron has a certain definite amount of energy, a portion of which it loses in the form of radiation when it passes to an inner orbit. The "transition probability" between two states of an atom is defined as the number of transitions per second from the upper to the lower state, divided by the number of atoms originally in the upper state. The mean life in the upper state can be shown to be related, in a simple manner, to the transition probabilities from that state to all of the lower states. In general, there are a number of different orbits or different conditions of the orbit corresponding to any one magnitude of the energy. Most readily realizable is the difference between a possible circular orbit and an elliptical orbit. On the elementary theory of the subject, for example, the condition of least energy of the electron is realized by an orbit in the form of a circle. The next higher state of energy is realized, as we go outwards, in the form of a circle or an ellipse, both having exactly the same energy upon the simple theory. The next possible energy

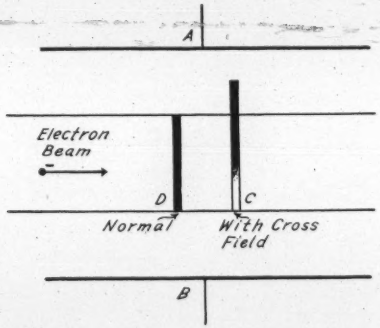
state is composed of three possibilities, a circle or two different ellipses, all again having the same energy. A more detailed examination of the theory reveals that these various orbits which have the same energy on a simple view of the situation in reality have slightly different energies but so little different that for many purposes it is convenient to dismiss that difference as negligible. However, there are other kinds of differences between these orbits, which are very significant. Thus, for example, the average time which an electron will remain in a circular orbit may differ vastly from the average time which it will remain in the elliptical orbit in which it has practically the same energy. Slight differences in one characteristic do not necessarily imply slight differences in all. Two men may be of equal weight and strength and have vastly different bank accounts. There are other differences between electrons in these orbits which are not even revealed by differences in the shape of the orbits themselves. There are differences in what is known by the awe-inspiring term "magnetic-quantum number." I cannot, in a brief space give a very adequate significance to this term. All I can say is that, according to the concept of modern atomic structure, if we pick out all those states of an atom which have the same energy each of these states is supposed to have an equal chance of coming into existence when the atom is excited in a state of normal temperature equilibrium. It is even customary to suppose that in other cases of excitation states of equal energy have equal chance of being produced. The only trouble is that with the "state" of the atom symbolized in the simple manner by its being an ellipse of a certain shape, the principle is not true. In order to make it true, we have to say that any one of the states can be realized in a number of different ways, each of which has an equal chance of occurrence for a given energy. Unfortunately, these different "ways" do not have any different characteristics to distinguish them from each other in the sense of their corresponding to orbits of different shape on the Bohr theory, for example. Only in the sense that mathematics provides for each of them a sort of ghostly attendant in the form of the "magnetic-quantum number" do they have any difference—but this ghostly attendant plays

no part in the shape of the orbit.[9] If, however, the atom is subjected to an external electromagnetic field, the different ways, which were the same except for the magnetic-quantum number, now have different properties as regards the effect of this external field. These different ways which look alike may be compared to a lot of brothers who closely resemble one another, weigh the same, etc., and show the differences of their temperaments only when annoyed by some external party. Now you see all of these matters are very complicated. Depending as they do upon theory, one might wonder very much how far the theory might hold when applied to such detailed matters. This would be particularly true when talking in terms of a theory which, as I have admitted, is not correct. However, the modern wave-mechanical theory has developed such a detailed story in regard to all of these matters, and it has been found correct in so many cases that it is of the utmost importance to test it in all possible ways to ascertain whether that correctness perpetuates itself in the most detailed consequences which it suggests. Now on the first occasion on which I reported upon Dr. Maxwell's work, he had confined his attention to that simplified picture of the phenomenon of emission of light which takes cognizance only of the energies associated with the orbits and discards differences which might result from a consideration of orbits which had the same energy but differed in other characteristics. In other words, the average lives which he obtained, while of the right order of magnitude, were representative of a sort of average condition appropriate to the energy of the orbit from which the electron fell in the process of light emission. Even treating the matter in this way, I showed in my report last year how Dr. Maxwell had obtained confirmation of the theoretical conclusions to the effect that the farther the electron was from the nucleus in its original orbit, the longer the mean life. Within the last year, he has been attacking this matter in a more refined manner in order to "get under the skin" of some of the more detailed processes involved.

[9] Of course, we should really discard the language of orbits and of the Bohr theory. If we do this, the difference in the states is no more mysterious as regards the magnetic-quantum number than it is in other respects. However, the whole subject then becomes too abstract for discussion except in mathematical terms.

It is desirable, first of all, to recall to you the general procedure in Dr. Maxwell's experiment. The experiment involves passing a beam of electrons through an evacuated tube containing helium. The electrons bombard the helium atoms, causing them to emit light which may be analyzed by a spectroscope into a number of different wave-lengths characteristic of the light emitted. By means of the spectroscope we are able to illuminate a vertical slit with the light and cause it to appear in another part of the apparatus as a number of slits with distinct colors, separated from each other. The positions of these colored images depend upon the wave-length of the corresponding light. In Fig. 14, the electron beam is shown

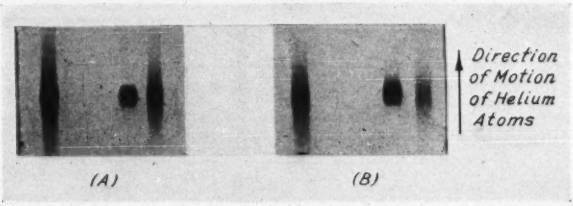
FIG. 14.



diagrammatically, and in Dr. Maxwell's experiment it passes between two plates *A* and *B*, between which an electric field could be established. Let us suppose that we focus the light from a certain portion of this beam on to the slit of the spectroscope, the slit being perpendicular to the direction of the beam, and let the two vertical lines *D* and *C* represent by their degree of blackness what we may expect to see in two representative cases. If the atoms which are excited to emit light are uncharged, then we may expect to see in our spectroscope a line which has the same intensity at the top as at the bottom, as in the case *D*. If, however, the act which excites the atom also removes another electron from it, the atom will start to

move upwards immediately it is excited, and when it emits light it will be farther from the lower edge of the beam than it was when the excitation occurred. The net result of all of this will be that the lower portion of the slit will be robbed of its light, and the upper portion may even be caused to extend beyond the boundary of the beam itself, as in *C*. If the life in the excited state is long, the disturbance will be great. Figure 15, *A*, shows three lines, the outer ones of which do not suffer any distortions by the electric field since they are known to be produced by non-charged atoms. The intermediate line, however, is produced by a charged atom and is capable of being distorted by the field. In Fig. 15, *A*, no field is applied. In Fig. 15, *B*, a field has been applied and has

FIG. 15.

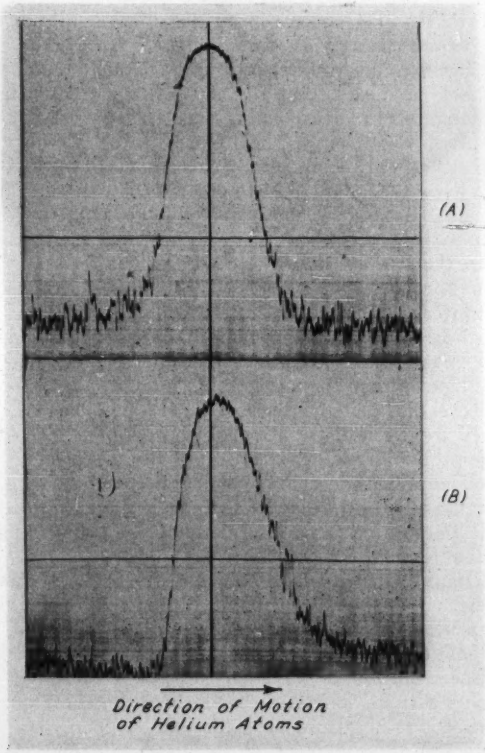


caused a disturbance of the photographic density. This disturbance is most easily exhibited by showing the densitometer records for the disturbed and the undisturbed line.[10] These are shown in Fig. 16. *A* is the undisturbed line, and *B* is the disturbed one. In the difference of shape and symmetry of these curves is contained some of the history of all the processes which have conspired to produce the difference. We should like to be able to read out of it the story of the transition probabilities between the upper states and all of the lower states to which transitions can occur. Unfortunately, we cannot dissect this much from the data. The transition probabilities between all of the states involved are different,

[10] The external lines simply serve as reference standards for aligning the two photographs in corresponding manner on the densitometer.

and there would be many ways of assigning different transition probabilities in such a way as to realize the same experimental data. However, with the exception of one consideration,

FIG. 16.



theory is perfectly definite in giving a precise value to the average rate of departure from the upper states or, what is the same thing, to the average life of the states. Thus we have a

definite means of calculating the results to be expected from the experiments. Although the agreement of the experiments with the calculations does not prove, uniquely, the truth of theory, the latter is at least supported in that the calculations are consistent with what is actually observed. I have stated that the theory of the experiment is definite at every point except that which concerns the distribution of the atoms among various states of the same energy. If we excite a number of atoms to a certain energy, then we have reason to believe, as I have said, that the states of different magnetic-quantum numbers corresponding to this energy will be equally distributed. However, as the atoms pass out of their various excited states, they soon destroy this equality of distribution, for the lives of some states are greater than those of others. However, it is possible, and is generally considered probable, that at each instant there is a readjustment of distribution between the various states, so that the relative distribution remains unchanged with time. This represents the extreme case of intermingling of the states, while a situation of no intermingling represents the extreme in the other direction. Dr. Maxwell has worked out for both cases the theoretical formulæ for the distribution of photographic intensity in his records. For the case of complete intermingling it is possible to calculate uniquely from the distribution of photographic density the average probability of departure from any given energy state and, incidentally, to test the agreement between theory and experiment as regards the distribution of photographic intensity. For the assumption of no intermingling, we can also test the agreement for distribution of photographic density, but we cannot calculate a quantity of the simple significance of the average mean life. We can only calculate a rather complicated expression depending upon the various mean lives.

In helium Dr. Maxwell has confined his attention to a single spectrum line of wave-length 2733×10^{-8} cm., which represents a transition from the sixth to the third quantum state, that is to say, from the sixth possible energy state that we encounter as we go out from the nucleus crossing the various states which are to be regarded as possible in the quantum theory, to the third possible state considered in the same sense. The sixth state can be realized in thirty-six different ways tak-

ing into account the magnetic-quantum number, and the third state can be realized in nine ways taking into account the magnetic-quantum number. There are, therefore, a great number of different transition probabilities between the different states. It turns out, on calculation, that the average probability of departure from the upper state is 0.85×10^8 sec.$^{-1}$. On the other hand, if we do not make use of the theoretical values of the transition probabilities as such but calculate the average probability of departure from the sixth stage in terms of the relation which theory provides between it and the experimental data, we find 0.90×10^8 sec.$^{-1}$ which consitutes a good agreement in view of the difficulties of the experiment.

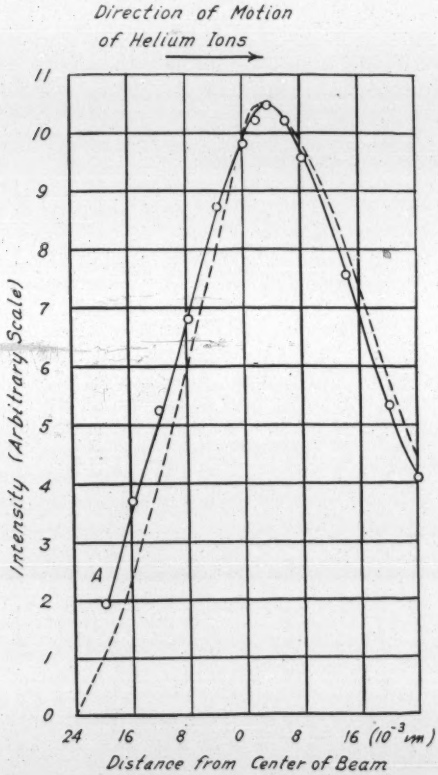
Again, Fig. 17 shows at *A* a reproduction of the experimental curve *B* of Fig. 16, and superposed on it the curve predicted by the theory.

The foregoing results have been calculated for the case of complete intermingling of the states. The case for non-intermingling presents certain complicated aspects which make it unsuitable for discussion except in the complete paper. Another refinement of a somewhat complex nature is that involved in taking into account, in the theory, what is known as electron spin. It would take us too far afield to discuss the significance of this matter here, and it will suffice for the benefit of those who are familiar with the technique of the mathematics to say that Dr. Maxwell has shown that inclusion of "spin" does not alter the values of the average mean lives deduced above.

One further refinement must, however, be referred to, as it involves questions which are recognized as vital features in work of this kind. A simple view of the mechanism of the origin of excited states in the atom takes account only of those excitations in which the electron is hurled into the excited orbit as a result of the external exciting agency. However, we have to recognize that some electrons may get into that orbit, because they have originally been thrown to outer orbits and have stopped there on their way back. A consideration of these cases complicates the theory of the matter to some extent. It requires more energy to throw electrons into these outer orbits so that if we excite the atom by means which are just sufficient to throw the electron into a certain particular

orbit, we can diminish the uncertainty involved. It is difficult to know whether one has excited the atom to just the right extent and to no more than the right extent for this purpose.

FIG. 17.



However, what Dr. Maxwell has done is this: He has excited the atom to a variety of different extents, ranging from that which is just enough to take the electron to the orbit which he

desires to take it to, to extents which are considerably greater than this. He has measured what we may call the apparent average mean lives for these various cases, expecting that the measured mean life would change with the magnitude of the exciting influence until with the least exciting energies, it approached a steady value representative of the true value. The results are shown in Table I. It will be observed that

TABLE I.

Energy of Electrons in Beam (Volts).	Average Life Experimental Values for Sixth Quantum State (Sec.)	Mean Average Life Theoretical Value Sixth Quantum State.
260	$1.6 \pm 0.2 \times 10^{-8}$	
120	$1.5 \pm 0.2 \times 10^{-8}$	
112	$1.3 \pm 0.2 \times 10^{-8}$	
100	$1.1 \pm 0.2 \times 10^{-8}$	
80	$1.1 \pm 0.2 \times 10^{-8}$	1.17×10^{-8} sec.

as the exciting energy given in the first column is diminished, the average mean life diminishes and approaches the theoretical value 1.17×10^{-8} seconds, which corresponds to the value 0.85×10^{8} sec. given for the average probability of departure from the excited state in question.

There is another way in which one may eliminate these uncertainties arising from the electrons' falling into the upper state under consideration from still more remote orbits. Luckily, the electron in the atom cannot do anything of any importance without emitting a shout in the form of the emission of light. In Dr. Maxwell's experiment, if the electron is thrown to some orbit farther out than the one he is studying and falls into that orbit, he will recognize that it has done this, by the emission of a definite spectrum line characteristic of the fall which it experiences. Therefore, the thought is to diminish the exciting cause and measure the apparent mean life for different magnitudes of the exciting cause, observing the intensity of those lines which owe their origin to electrons which have been thrown to orbits outside of the one under examination, with the hope that as the intensities of these lines diminish the measured mean life will approach a limiting value characteristic of the condition when no such lines are produced. Now, as a matter of fact, this is not exactly what Dr. Maxwell has done, because the lines which are produced by fall of electrons from what I have called the outer orbit

to the orbit under investigation are of such long wave-lengths that they are beyond the limits which are easily recorded by the spectrograph. However, we know that any falls of electrons from outer orbits to the orbit under investigation will also be accompanied, of necessity, by falls of a certain number of them from those outer orbits to orbits which are still nearer the nucleus. The light corresponding to these can be recorded on the spectrograph. It resulted that, as the exciting voltage was diminished, the intensities of the lines originating in levels above that which Dr. Maxwell was studying diminished, until, finally, these lines practically disappeared, while the lines from the level under investigation remained visible. This is further evidence of the validity of the assumption that the experiments are free from uncertainties arising from electrons falling into the state under investigation from orbits more remote from the nucleus.

Experiments of this kind are, of course, extremely difficult in the matter of dissecting the various mutually disturbing influences and phenomena involved. However, it is safe to say that Dr. Maxwell's conclusions are in harmony with the direct predictions of the wave mechanics to a degree which provides a significant confirmation of that theory in a realm which draws in a particularly detailed way upon the conclusions which are characteristic of its nature.

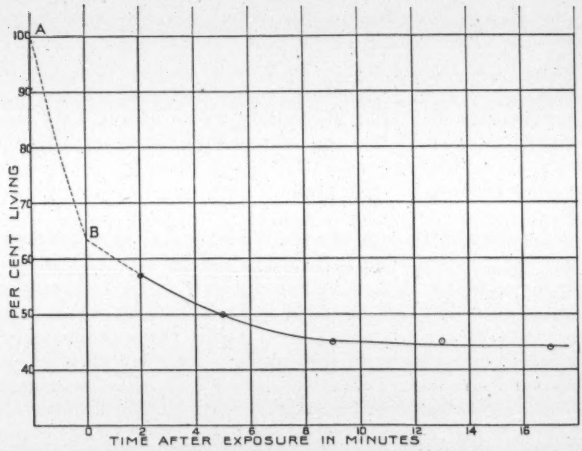
EXPERIMENTS ON THE EFFECT OF RADIATIONS IN CAUSING DEATH IN LIVING CELLS.

Last year I cited some experiments which Mr. del Rosario and I had been carrying out, concerned with the mechanism of the process by which alpha particles cause death in a living cell which they strike. The cells investigated were cells of euglena, because it was easy to tell when they were alive by the movements which they exhibited. The general procedure was to mount some of the euglena cells in a liquid under a microscopic slide. A thin glass tube containing radium emanation was introduced into the liquid. By breaking the tube, the emanation was allowed to dissolve, and the alpha particles emitted could bombard the cell. Under these conditions, the rate of death of the cells was proportional to the number present, a result which enabled us to conclude that death was

caused by a single impact with some sensitive entity in the cell itself rather than by a process in which two or more impacts were necessary with possibilities of recovery between them. Moreover, it was possible to go still further, and by estimating the amount of emanation in the liquid, to deduce the actual size of the sensitive entity which, when struck by the alpha particle, caused death. It was very interesting to find that the size of the entity was about equal to that of the nucleus of the cell. Since the time when these experiments were performed, Mr. del Rosario has extended the investigation to the use of ultra-violet light as the agent to cause death in the cell. Certain very characteristic differences from the results obtained with alpha particles immediately made themselves evident. In the first place, it was noted that the rate of death of the cells was not related in an obviously simple manner to the intensity of the light and to the number present, but it was affected by the time that the light had been in operation; cells did not cease to die immediately the light was shut off. It was as though the light made them sick, causing them to wander off and die subsequently of a sort of premature old age. On the other hand, Mr. del Rosario found that if he applied the light for a certain time, estimated the total quantity of light which had fallen upon the cells and then counted the total percentage of cells which had died as a result of the exposure to that light, taking account of the fact that many of the deaths occurred some time after the light was removed, then a very definite proportionality was obtained between the percentage of the cells which had been killed and the total amount of light to which they had been exposed. The results in this connection are well illustrated by the following figures. I wish first to call your attention to Fig. 18, in which the horizontal axis represents the time and the vertical axis the percentages of the original number of euglena cells still living. We start before the application of the light and, of course, the percentage living is unity. Then, at the point A, for a period of two minutes during which time no observations were taken, light was applied. The light ceased to be applied at $t = 0$. Then, as will be seen, the death of the cells continued quite actively for a period of the order of 10 minutes or more. Fig. 19 shows the logarithms of the number of cells living

divided by the total number plotted against the amount of light to which the cells had been exposed, as represented by the product of the radiation intensity and the time of exposure. It is easy to see that the linearity of this graph corresponds to the conclusion that the percentage of the cells killed by the radiation is proportional to the total amount of the radiation to which they had been exposed in the sense in which I have already indicated. It may be worth while to

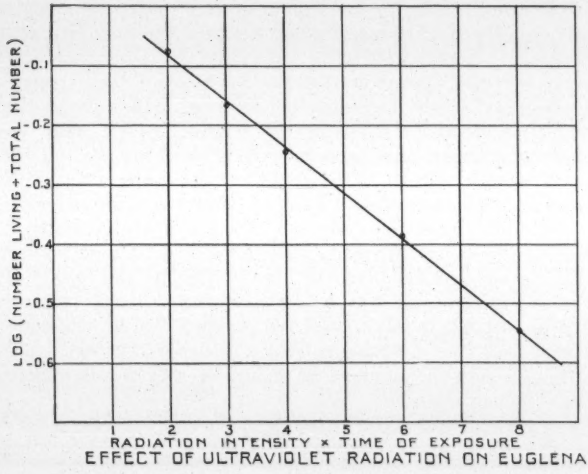
FIG. 18.



state that the experimental procedure consisted in examining the euglena cells under a microscope, the cells being covered by a quartz microscopic cover slip so as to transmit the ultraviolet light. The rate of death was observed before the ultraviolet light was applied. Then light of measured intensity was applied for a certain definite time, and the total number of cells which died was subsequently counted. It was then necessary to discard the specimen completely, start with a new set of euglena and repeat the experiment for another total quantity of light as represented by the product of the intensity

and the time. In this way the various points for curves like Fig. 19 were obtained. Incidentally, it may be of interest to remark that, in accordance with what I have already implied, the number of cells killed depended only upon the intensity of the light multiplied by the time of application and was otherwise independent of the intensity itself. In other words, if one takes a certain intensity I for the light and makes exposure for a time t, he gets the same result as if he makes an

FIG. 19.



EFFECT OF ULTRAVIOLET RADIATION ON EUGLENA

exposure for ten times the intensity I for a time one-tenth t. Speaking from the point of view of the quantum theory of light, we may say that the quantity which determines the number of deaths is the number of quanta of light which have struck the container under observation. One might have supposed that this result was so evident that it would hardly be worth while to call attention to it. However, such a law is not strictly true in the case of photographic action, for example. It is not a fact that the amount of blackening produced by an

intensity I applied for a time t is the same as that of an intensity 10 I applied for the time one-tenth t.

Now, of course, ultra-violet is rather a vague term, since a whole range of different wave-lengths is contained in what is ordinarily called ultra-violet light. The source of light used by Mr. del Rosario was a quartz-mercury arc. This contained, in addition to several lines of small intensity, four lines of strong intensity at wave-lengths 3654, 3132, 2894, 2536 angstrom units, an angstrom unit being 1/100,000,000 of a centimeter. So Mr. del Rosario used what is called a monochromatic illuminator for separating out these wave-lengths so that they could be used independently. He then proceeded to make investigations with individual wave-lengths rather than with the ultra-violet light as a whole, and an extremely interesting result immediately followed. Line 2536 was strongly effective in killing the euglena. Line 2894 was slightly effective, and the others were, to all intents and purposes, without effect. This is true in spite of the fact that the 2536 and 2894 are weaker than the other two lines as regards actual light intensity. Mr. del Rosario next proceeded to measure the actual quantity of light passing through his containing cell as a result of the illumination by the lines. He did this in the usual way by allowing the radiation from the line in question to fall upon a thermopile which he afterwards standardized by radiating it from a source which was so constructed that the amount of radiation which was emitted could be calculated.

Having obtained the intensity of the light, it was possible, by the use of certain readily acceptable hypotheses to calculate the size of the sensitive entity for killing by ultra-violet light in a manner analogous to that adopted for the case of killing by alpha particles. The nature of the calculation is somewhat different, because the range of the alpha particles is so small that all of them emitted in the liquid are absorbed in the liquid, whereas in the case of the ultra-violet light only a portion of the light falling upon the container is absorbed, and we have to estimate the amount absorbed by allowing for the coefficient of absorption of ultra-violet light in the liquid. When all is properly taken into account, it turns out that if δM is the number which has been killed and M the

number originally present, then

$$\frac{\delta M}{M} = \lambda N v,$$

where λ is the coefficient of absorption of the light in the material of the living cell, N is the total number of quanta of light which fall upon unit area of the container during the killing and v is the volume of the sensitive entity. The two spectrum lines which produced appreciable killing were those of wave-lengths 2536×10^{-8} and 2894×10^{-8}, respectively. The corresponding values of $\delta M/M$ and N are given in Table II.

TABLE II.

Wave-length of Line, cm.	$\frac{\delta M}{M}$.	N.	λ.	Radius of Sensitive Entity.	ρ.
2536×10^{-8}	3.7×10^{-2}	7.5×10^{13}	3×10^{2} Max. 2.5×10^{-5} Min.	1.7×10^{-5} cm.	3.6×10^{-4}
2894×10^{-8}	1.5×10^{-4}	3.3×10^{13}	3×10^{2} Max. 3.5×10^{-3} Min.	0.7×10^{-5} cm.	2.5×10^{-5}

In order to calculate the size of the sensitive entity, it is necessary to know λ for the entity. Mr. del Rosario has photographed the cells in the monochromatic light of each of the lines concerned, and he has also photographed the surrounding water, in each case by transmitted light. By taking densitometer measurements of the photographs at different spots, and by making suitable standardizations, it is possible to calculate, for each line, the value of λ appropriate to any part of the cell in terms of the value of λ for water, which value can be obtained from tables. Table II then gives the maximum and minimum value of λ for the cell for each of the wave-lengths which were effective in killing. It also gives the corresponding size of the sensitive entity. It will be seen that taking even the minimum value for λ, the size comes out as corresponding to a radius of 1.7×10^{-5} cm. in the case of the 2536 line, whereas the size for an alpha-particle killing was 2.4×10^{-4} cm., a quantity 16 times as large. For the larger value of λ the discrepancy is still greater. However, a further key to the situation is given by the fact that the sizes are quite different

as determined from the wave-length 2894 for corresponding λ's. This raises a criticism on our original postulate that each quantum absorbed causes death. Suppose that we assume that death is caused in only a fraction p of the cases of absorption of a quantum. Our formula then becomes

$$\frac{\delta M}{M} = p\lambda N v.$$

If we should now assume the same value of v as for an alpha-particle killing, we could calculate the value of p for each case. These values are given in the last column of Table II.

Of course, we may not be correct in assuming that the size of the sensitive entity for an alpha-particle killing is the same as that for ultra-violet light killing; but while there must remain, at this stage, certain variations as to the exact significance of the results as regards the size of the sensitive entity, we, at least, have laid hold upon the phenomenon in such a way as to pin it down to a small number of possibilities.

EXPERIMENTS ON THE VARIATION OF THE SPECIFIC HEATS OF GASES AT CONSTANT PRESSURE WITH PRESSURE.

Now, as an illustration of an entirely different kind of investigation in progress at the laboratory, I wish to describe some experiments by Dr. Workman upon measurements of the variation of the specific heats of gases with pressure. If an apology is necessary, I respectfully crave it for reminding you that the specific heat of a substance is the quantity of heat required to raise the temperature of one gram of it one degree at a standard temperature. The major features of a gas can be accounted for by supposing it to consist of nothing but a set of molecules, flying about in space, and with properties corresponding to those of hard elastic spheres. These spheres bump against each other occasionally and rebound in such a manner that the combined kinetic energy of the spheres after the rebound is the same as before. I need hardly remind you that, on this view of the mechanism of a gas, the pressure of the gas arises by the continual bombardment of the rapidly moving molecules against the walls of the enclosing chamber. Just as the impact of a stream of sand upon the hand gives rise to the sensation of a steady pressure, so the much more

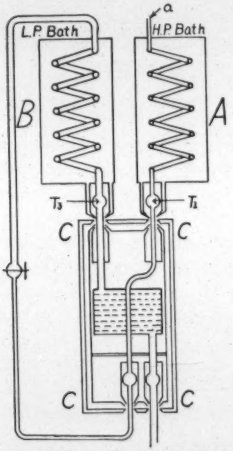
frequent impact of the gas molecules against the walls of the container produces the equivalent of a steady pressure. On such a view it is easy to see why the pressure is doubled on halving the volume, because the number of impacts with the walls is doubled. On a view which regards the temperature of a gas as synonymous with the average kinetic energy of its molecules, we can readily see why it should be that the pressure of a gas should increase proportionally to the temperature.

On this simple view of the mechanism of a gas, the specific heat of a gas at constant pressure should be independent of the pressure. If, however, the molecules exert forces on each other when in each other's immediate vicinity, the specific heat of the gas should depend upon the pressure. The story is one which is too long and complicated to enter into in detail now. It will suffice to say that the variation of the specific heat of a gas with pressure provides very fundamental information bearing upon the nature of the forces between molecules and of the atomic and molecular structure which it is necessary to attribute to the molecules in order to account for them.

For overcoming many of the sources of error naturally inherent in measurements of quantities of heat, particularly those associated with gases Dr. Workman has utilized an ingenious method, founded upon a scheme used by H. L. Callender for liquids. I shall not enter into the details of the experiment further than to the extent represented in the simplified diagram Fig. 20 which illustrates the general principle. A is a bath at the temperature T_1. B is another constant temperature bath at a temperature T_3 and $CCCC$, which we shall call a mixer, is a bath which is at an intermediate temperature T_2. The gas at high pressure passes through the bath A where it assumes the temperature T_1, then it passes through a mixer, after which its pressure is reduced by means of a throttle and it is caused to pass through the bath of temperature T_3. It is then passed once more through the mixer and out into the air. If there were no heat loss or gain by the mixer except from the gas itself, we could truthfully say that the heat lost by the gas in falling from T_1 to T_2 was equal to the heat gained by the same quantity of gas in rising from the temperature T_3 of the cold bath to the temperature T_2 of the

mixer; and if the specific heat of the gas at high pressure were equal to that at low pressure the mixer would eventually come automatically to a temperature T_2 which is just half way between T_1 and T_3. If it comes to any other temperature, the result is evidence of a variation of the specific heat of the gas with pressure and the departure of the temperature from the mid-temperature $(T_1 - T_3)/2$ provides the means of determining the change of specific heat from one pressure to the other.

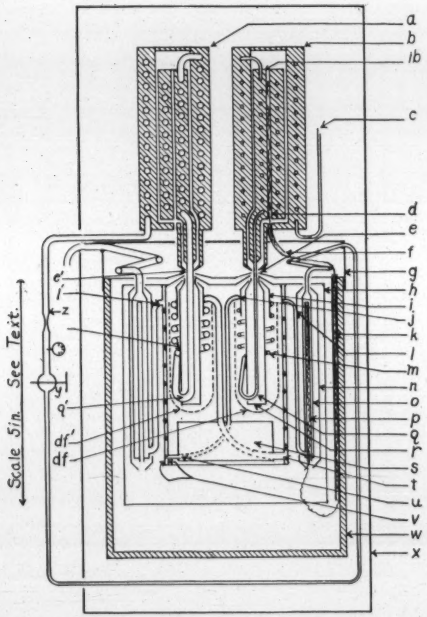
FIG. 20.



Heat loss, which may occur from the mixer, can be eliminated to a very high degree of accuracy by reversing the flow of the gas so that it passes through the cold bath at the higher pressure and departs from the hot bath at the lower pressure. A combination of the results of the two experiments enables the heat losses and other uncertainties of the experiment to be eliminated and very accurate results to be obtained for the variation of the specific heats of the gases with pressure. Figure 21 is a detailed section of the actual apparatus which is very elaborate as regards its details, and I will not take

time to describe it now. I must pass on to the actual results obtained. They are summarized [11] in Fig. 22 in which the ordinates represent the ratio of the specific heat C_p at the pressure p to the specific heat $C_p = 1$ at atmospheric pressure, and the abscissæ represent the molecular density of the gas,

FIG. 21.



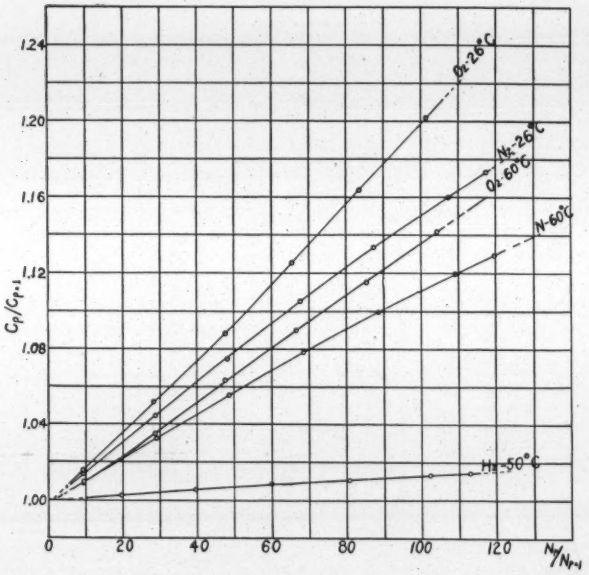
which quantity is approximately proportional to the pressure. It will be observed that, for Oxygen and Nitrogen, the data have been obtained for two temperatures, 26° C. and 60° C. To these curves should also be added another recently ob-

[11] Dr. Workman's paper in the *Physical Review*, 37, 1345, 1931, gives a full account of these experiments.

tained for helium, and showing an immeasurably small variation with pressure over the whole range of pressure employed.

There is not much to say regarding these curves except that the departure of the curves from straight lines parallel to the horizontal axis contains the information for one of the most fruitful attacks that we have upon the nature of inter-

FIG. 22.



molecular forces. The situation is particularly important because the tendency of theory is to lead to variations of C_p with pressure which are smaller than these. The situation as regards helium is also of considerable interest as indicating that the atoms of this monatomic gas act like the hard, elastic spheres of elementary theory. The atoms exert very little influence on each other until they come suddenly into contact.

It may further be added that Dr. Workman has recently measured the specific heats for carbon dioxide and finds an enormous change amounting to a factor of ten in the specific heat over the range of atmospheric pressure to 100 atmospheres at 45° C.

The modern wave-mechanical theory of molecules possesses the power to go much further in the direction of predicting the influence of pressure upon specific heat than was possible with the older theories, and Dr. A. Bramley and the present writer are engaged upon an investigation into this field, with a view to utilizing the experimental data in conjunction with the theoretical material for the purpose of securing the the harmonization between the two.

RADIATION FROM BODIES OF SMALL SIZE, AT LOW TEMPERATURES.

In the gradual evolution of the laws of atomic phenomena, the situation has been one where we became familiar at first with the forms of the laws of nature applicable to matter in bulk, and then gradually ferreted our way into the region of smaller things where we found that those laws apparently did not hold. We were then forced to formulate other laws for the smaller things, laws which demanded that the mechanism of our thoughts should assume a form quite different from that which seemed to us originally as appropriate to large-scale phenomena. And yet, those large-scale phenomena must be capable of description in terms of the laws for small things like atoms and molecules. It may be a happy accident that things have smoothed themselves out for the laws of matter in bulk, so that much of their atomic nature has disappeared, causing them to take a form which is, on the whole, simpler than that which they would have had if expressed completely from the atomic standpoint. On the other hand, the fact that such simple laws may fit with practical accuracy the behavior of things on a large scale, does not relieve us of the necessity of seeing how those large-scale phenomena may be spoken of ultimately, if we so wish, in terms of the laws of atoms and molecules. I have sometimes thought of the analogy of the laws of a city. Let us imagine a giant looking down upon the city. He sees what appears to him as a curious phenomenon: There is an odd contraption in the center of the

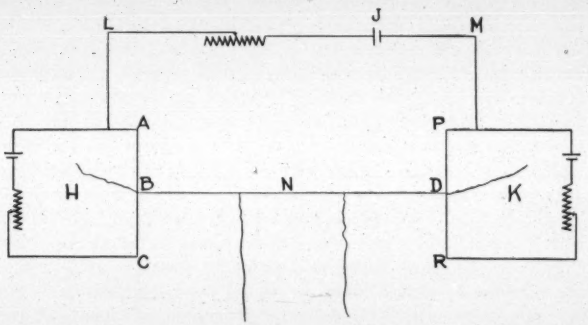
road which flashes lights of different colors. When it shows a red light, automobiles approaching it come to rest. When it shows a green light, the cars continue with undiminished velocity. When the light is yellow, the cars always turn to the left (never to the right), etc. One who tries to discuss the laws of the atom in terms of the laws that he has thought of for matter in bulk, is somewhat in the position of the giant who sees this phenomenon of the traffic light and the other phenomena concerned with the city, and then, getting down to the stage of trying to discuss the mechanical properties of some of the bricks of which the houses are constructed, tries to introduce into the mechanism of those bricks traffic lights with red and green signals, policemen to direct the molecules, and so forth. We know that the reverse process would be possible. In terms of the properties of atoms, molecules, bricks, etc., it would be possible to explain quite satisfactorily the behavior of the traffic lights, but it would be very difficult to turn the matter around the other way and discuss the properties of atoms and molecules and of bricks in terms of the properties of traffic lights and city government.

Now it is very interesting to see whether we can actually construct things which are so small that they begin to lose some of the smoothed-out properties applicable to matters in bulk and partake of the characteristics peculiar to atomic phenomena. The light radiations which an atom emits are determined by the various energy states which it is possible for the atom to assume, and the determination of these energy states in the atoms is one of the things which is most characteristic of the difference between atomic laws and those which we have formerly used for matter in bulk. A body, unless it is at the absolute zero of temperature, is continually in the act of radiating heat. The heat which it radiates is of all sorts of different wave-lengths, ranging from great length to extreme shortness, passing, in fact, into the optical region. The distribution of the energy of the heat radiation among these different wave-lengths has always been a problem of fundamental interest to the physicist. Theory shows that the character of the radiation which is emitted in wave-lengths which are short as compared with the dimensions of the emitted body, is practically independent of the shape of that

body, and depends only upon the fundamental characteristics of atomic phenomena as a whole and upon the nature of the atoms of which the body is composed. It is even independent of this latter feature to a large extent and completely independent of it for that particular type of body known as a black body. However, when we come to wave-lengths which are comparable with the dimensions of the radiating body, then theory raises the question as to whether the size of the body should not play a part. In fact, if the wave-length is longer than a quantity comparable with the dimensions of the radiating body, then the radiant energy emitted in such wave-lengths should, according to certain reasonable views, be less than for a larger body; and, as a matter of fact, the detailed story of the radiation emitted for such wave-lengths should involve a situation in which we actually see a phenomenon of atomic origin—the radiation—interplaying with, and controlled by, the dimensions of a thing of observable size. As we lower the temperature of a body, the amount of radiation which it emits in the longer wave-lengths becomes greater and greater in comparison with that emitted in the shorter wave-length, so that if we should measure the radiation from a body which is small in some of its dimensions—a body such as a thin wire—these phenomena depending upon the smallness of the dimension should start to reveal themselves as the temperature is lowered. We have made some experiments on this matter and have measured what is called the emissivity for a wire 1/100 of a millimeter in diameter at various temperatures ranging down to temperatures 160° C. below that of melting ice. The plan was to pass an electric current through the wire and measure the power supplied to it in order to keep it at the temperature desired, that temperature being determined by a measurement of its electrical resistance. The electrical resistance could be obtained by measuring the current flow and the difference of potential between the ends of the wire. Simple as the experiment is in theory, very many difficulties enter in practice. The greatest of these concern the tremendous amount of conduction which occurs along such a wire in comparison with radiation and low temperatures. Thus, for example, at a temperature of 153° below zero, the amount of heat conducted out of the ends of a platinized copper wire

20 cms. long and with a diameter of 1/100 of a mm. is about four times the heat radiated from its surface when the surrounding temperature is minus 180°. In order to eliminate the difficulties, the plan shown in Fig. 23 was adopted. *BD* is the experimental wire 1/100 of a mm. in diameter. The two circuits *H* and *K* provide a means of heating the wire *AC* and *DN* so as to keep up the temperature of end of the experimental wire *BD*. The main current which heats the experimental wire *BD* is supplied by battery *J* through the circuit *LMN*. The criterion that the points *B* and *D* are set at a

FIG. 23.

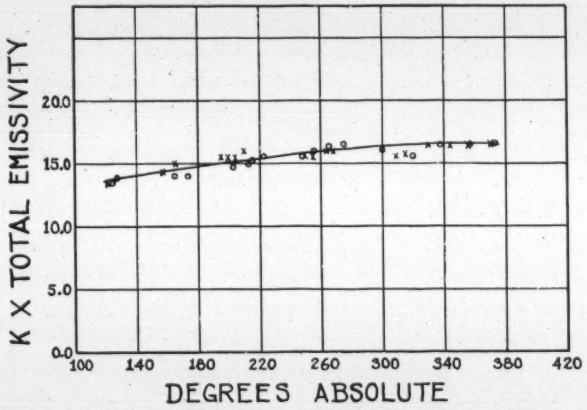


temperature sufficiently high to prevent any conduction into the wire or out of it from outside is that the potential drop between the various leads are in the ratio of the length of the wire between them.

Figure 24 represents the results for a constant times the emissivity plotted as a function of the temperature for two wires, 0.2 mil and 0.5 mil in diameter, coated with platinum black to diameters of 0.4 mil and 0.8 mil respectively. The significance of these sizes will be clear from the statement that at 160° absolute more than 98 per cent. of the heat radiated from the 0.4 mil wire would exist in wave-lengths longer than the platinized diameter of the wire. In Fig. 24, adjustment of the scale has been made so that the curves correspond for one temperature. It will be seen that when this has been

done, the points for the two wires lie on a common curve as accurately as do the different points for one wire. If the dimensions of the wire as a whole played a significant part in the radiation in such manner as would be suggested by classical theories or by conservative extensions of them to the realm of the quantum theory as applied to the wire as a whole, the curves would be quite different for the two wires. In fact, the heat radiation seems to know that it is an atomic phenomenon

FIG. 24.

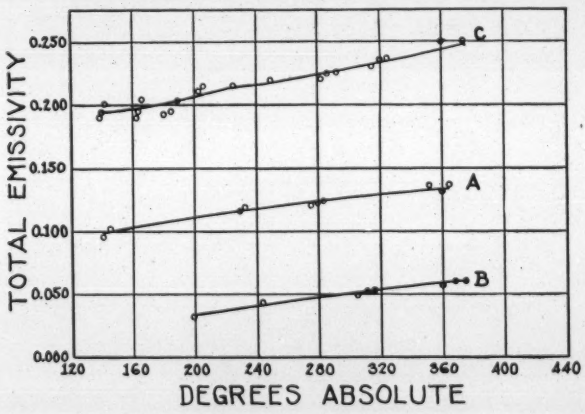


and will not be deceived into utilizing for its realization a mechanism which, at first sight, might seem well adapted to its needs. Thus, curve *C*, Fig. 25, is for a wire for which the fundamental wave-length emitted corresponding to its radial dimensions is about 7.5×10^{-4} cm. As a classical oscillator, it could not emit any radiations longer than this except by its longitudinal oscillations. At the temperature 400° absolute, 68 per cent. of the radiation exists in wave-lengths which are longer than 7.5×10^{-4}; at 160° absolute, practically all of the radiation exists in wave-lengths longer than 7.5×10^{-4} and so could not be emitted at all by the transverse oscillations of the wire treated as a classical oscillator. It is true that the

emissivity of the wire shows a change of 33 per cent. over this range of tempterature of 160° to 400° aboslute, but this change is comparable with the change shown over the same range of temperature by wire A, whose diameter is 26×10^{-4} cm., a diameter such as would permit the transverse oscillations of the wire to lie within the range important for heat radiation over the whole range of temperatures covered.

Another consideration pointing to the lack of influence of the dimensions of the wire upon the phenomena is the effect of the surface itself. Even in the case of these thin wires at

FIG. 25.



low temperatures where, in the classical sense, the heat oscillations are comparable in wave-length with the fundamental modes of electrical oscillation of the wires treated as perfect conductors, the surface with its highly improved conductivity still plays a controlling part in determining the radiation. Thus, on omitting the blackening of the surface, the apparent emissivity of the material of the wire falls by a factor of about eight. Even minor variations of the surface of the wire are extremely important, variations which concern only a few molecules of thickness and such as may be produced by ex-

termination of the surface by grease from the grease vapors in the apparatus. Thus, curves *A* and *B*, Fig. 25, represent the same wire, but curve *A* corresponds to the case where the wire was merely cleaned, but was subjected to grease vapors from the apparatus, while *B* corresponds to the case where there was no grease and the apparatus and wire were thoroughly baked out.

Speaking generally, we may say that when proper precautions are taken to avoid spurious heat losses or gains, the law of variation of emissivity with temperature for these thin wires at low temperatures where the wave-lengths concerned are comparable with the diameters of the wires is the same as obtained by other observers for much higher temperatures, where the wave-lengths principally concerned in the heat radiation are very short compared with the diameters of the wires used.

The mathematical theory underlying the various probabilities concerned with what the quantum theory would predict for the radiation from these curves has been developed but is too complicated to reproduce here.

FURTHER EXPERIMENTS NOT INCLUDED IN THE REPORT AS PRESENTED VERBALLY.

ENERGY LOSSES OF ELECTRONS ON REFLECTION FROM SOLIDS.

I have already referred to Dr. Johnson's experiments on the reflection of atomic hydrogen from crystals. I now turn to an investigation having a close relation to that subject and concerned with the reflection of electrons from solids. These experiments are being carried on by Dr. E. Rudberg, who is working with us under the auspices of the Rockefeller Foundation.

It has been known for some time that when electrons are allowed to fall on a solid conductor some of them are scattered back from the surface without having suffered any loss of speed. In some earlier work, Dr. Rudberg measured the velocities of the electrons leaving such a bombarded target, using a method of magnetic deflection. For several different substances tested, he found that, in addition to the well-defined group of "reflected electrons" just mentioned, there was a continuous distribution of electrons of lower velocities,

corresponding to inelastic collisions in which the bombarding electrons gave up part of their initial kinetic energy to the target. An interesting thing about this continuous distribution is that it exhibits small maxima, corresponding to definite energy losses, which are independent of the velocity of the bombarding electrons. If the number of electrons per unit range of velocity is plotted with respect to kinetic energy of the scattered electrons, these maxima always appear at a constant distance from the sharp peak of reflected electrons. Such a representation may be termed an energy-loss spectrum. Of the substances tested, each had its own characteristic energy-loss spectrum. In these experiments, the targets were kept at incandescence during bombardment. Preliminary experiments had indicated that when the targets were kept cool the characteristic features disappeared, all substances yielding essentially the same smooth energy-loss curve.

The present experiments have been concerned with a target of nickel, a metal not previously tested. A large nickel crystal was used, since it was also intended to make some experiments on the possible influence of crystal orientation on the loss spectrum. For the same reason, the apparatus was constructed with both electron gun and target movable from the outside of the tube by means of a ground glass joint, attached to a system of gears inside, and a magnetically controlled gear-shifting device. This makes it possible, (*a*) to vary the angle of incidence of the bombarding beam, (*b*) to measure the velocity of electrons escaping in different directions from the crystal, and (*c*) to turn the target through 360° around the normal to its surface. The target could be heated by a small tungsten-wire furnace behind the crystal. For the velocity measurements, a narrow beam of electrons selected by a fine slit was deflected on to a second fixed slit by means of a transverse electric field, applied between two coaxial cylindrical plates. Behind the second slit was a collector connected to the electrometer. The voltage applied across the plates gave a measure of the energy of the electrons passing through the second slit.

In order to avoid the deposition of substances from the hot cathode on the bombarded surface, the former was situated out of the line joining the slit system to the surface, and elec-

trostatic deflection was used to cause the electrons to pass through the slit. With a straight electron gun, using a tungsten filament of high temperature it is possible to prevent the formation of a tungsten deposit by keeping the target at a temperature near to incandescence. When the target remains unheated or when an oxide-coated filament is used, the straight electron gun soon covers the target surface with a layer of foreign material.

A number of distribution curves for the scattering from the (111) face of a nickel crystal have been measured, for different bombarding voltages. They show that this substance, like those previously investigated by the magnetic method, has an energy-loss spectrum with characteristic maxima independent of the bombarding voltage. There are two such characteristic maxima corresponding to energy losses of about 3.8 and 5.7 volts respectively and separated from the reflected peak by a sharp minimum. On the side of lower velocities, there is a flat minimum, followed by a rise to a very broad maximum, similar to what has previously been found for most targets.

Changing the temperature of the target alters the loss spectrum in the following way: With no heating current to the furnace, the two characteristic maxima disappear almost entirely. The distribution curve is very low in this part but rises to the broad maximum for lower velocities, just as the cold target curves in Dr. Rudberg's earlier experiments. A very moderate heating, presumably to 200° C., is sufficient to change this curve into the hot target curve with its characteristic maxima, but increasing the heating by a factor of 15 does not produce any further change. It is probable that the "cold-target distribution" is produced by a thin layer formed on the target from the gas residues in the tube, but no trace of a visible deposit could be detected.

Some peculiar effects have been found with respect to the relative magnitude of the two maxima at 3.8 and 5.7 volts. Several distribution curves were measured with a heating input of 10 watts, such as to make the target cherry red. In these, the higher loss was very clearly developed, but the 3.8 maximum was so faint that it was entirely overlooked. The input was then raised to nearly 15 watts, which brought out this maximum also, but the higher loss was still the more

prominent of the two. In subsequent runs at all lower heating inputs, these maxima remained in the same ratio. Prolonged heating at 15 watts and higher brought out the 3.8 volt maximum better, but soon a final state seemed reached with both maxima about equally strong. At first it was suspected that at the high temperature a short rise in pressure might have taken place and some heat-resistant compound might have formed on the target surface. The tube was, therefore, opened up and the target, which appeared perfectly clean and highly reflecting, was etched with nitric acid, thoroughly washed, and after re-assembling and baking, again tested. The result was that both maxima appeared as before, independent of the heating current. In subsequent experiments, the target was heated to such temperatures that considerable evaporation of nickel seems to have taken place, as judged from the appearance of the other metal parts in the vicinity, but the two maxima still remained. At the present stage it seems, therefore, that they should both be ascribed to nickel. Further experiments are now being started, using a polycrystalline piece of nickel which may give more information about this question.

The experiments on the possible influence of crystal orientation are still in a preliminary state. It has been definitely proved, however, that the characteristic energy-loss curves can be produced for all orientations of bombarding beam, crystal, and scattered beam used for velocity measurements, and that the position of the characteristic maxima remains unchanged.

The story of the losses of energy of electrons on bombardment of a surface is one which involves those particular processes which come into play when electrons come near to atoms. It is one which has, therefore, a direct bearing upon some of the most characteristic features of atomic processes, and the facts revealed in such investigations must be accounted for and so provide a check upon any theory of atomic structure which claims to tell the story of such processes.

EXPERIMENTS ON THE EFFECT OF HYPERFINE STRUCTURE ON THE POLARIZATION OF CADMIUM RESONANCE RADIATION.

Certain spectral lines show what is known as hyperfine structure. In some cases a line that appears single under

ordinary spectral resolving power is found to consist of several lines, very close together, when observed under high resolving power. The several lines thus appearing are called "components." Recently, physicists have explained these hyperfine structure components by assuming that the nucleus of the atom is spinning and has a certain spin moment. Perhaps I ought to qualify, to some extent, this idea of spin. It would be stretching our imaginations to too realistic a picture to think of the nucleus as a ball spinning about its axis as a base ball spins. All we can say is that by suitably enriching the mathematical structure which in wave mechanics represents the atom, we can make it account for the experimental facts, and the enrichment necessary in the present instance bears a close analogy to what we should do in an ordinary mid-Victorian dynamical problem were we to change our equations from those appropriate to a stationary central nucleus to one which was spinning about an axis. The terms "moment of spin," etc., have only a mathematical significance in the modern problem, however.

The spin moment of the nucleus combines with the spin moment of the electron and with the orbital momentum of the electron to make up what is called the total angular momentum of the atom. It has been known for some time that, by attributing to the electron these characteristics of "spin," we can set up a satisfactory theory which determines whether a given spectrum will consist of singlets, doublets, or triplets. In a similar manner, the nuclear spin determines the number of hyperfine structure components.

Any given nucleus always shows the same spin measured in units of $h/2\pi$, where h is Planck's constant, and this spin is known to depend upon the number of protons in the nucleus. Isotopes of the same element may show different spins. If the number of protons in the nucleus is an odd one, the nuclear moment is usually an odd multiple of $h/4\pi$; whereas if the number of protons is even the nuclear moment is usually zero.

When a gas is subjected to the influence of radiation of a wave-length equal to that which the gas itself would emit if excited, the atoms of the gas become excited and re-emit the radiation in question. Such re-emitted radiation is known as

"resonance radiation." If the original light is polarized, the resonance radiation is polarized, partially at any rate. The extent of the polarization is, according to modern theory, determined by the total angular momentum of the atom. If nuclear spin is neglected, theory leads to the conclusion that for the resonance line of wave-length 3261 angstrom units observed by exciting cadmium vapor, the polarization should be 100 per cent. However, the best experiments have always shown less than this amount.

Cadmium has a number of isotopes, and it has been shown from measurements on the hyperfine structure of cadmium that the isotopes of even atomic weight have a nuclear moment $i = 0$, while those of odd atomic weight have a nuclear moment $i = 1/2$ (in units of $h/2\pi$). These hyperfine structure measurements have been made with great care on the visible triplet in cadmium. Assuming the values of i from the visible lines, one can show that the 3261 line of cadmium should show three components, one with $i = 0$ and two with $i = 1/2$, and it is possible, in terms of the wave-mechanical theory, to calculate the polarization to be expected.

Dr. Mitchell has made the calculation for the case when the electric vector of the exciting light is polarized parallel to a magnetic field placed on the resonance bulb, and when the electric vector is perpendicular to it; also for the case where the source is a "broad-line source" [12] and when it is a "narrow-line source." The results are given in the table in which θ is the angle between the electric vector of the exciting light and the direction of the magnetic field placed on the tube.

TABLE III.

Percentage of Polarization.

	$\theta = 0$.	$\theta = \pi/2$.
Broad Lines	81.9%	69.4%
Narrow Lines	96.4%	93.0%
Experiment	73%	85%

[12] The terms "broad-line source" and "narrow-line source" are technical terms. The former denotes a situation where the "line" extends over a finite region of wave-length with an intensity which is practically uniform for considerable distances on either side of the true resonance wave-length. In the "narrow-line source" the intensity varies more rapidly, and in a manner which is definitely calculable.

The results are in agreement with the experiment as regards order of magnitude, which is as much as can be expected.[13]

THE RELATION BETWEEN THE PHOTOELECTRIC AND THERMIONIC WORK FUNCTIONS OF SIMPLE COMPOSITE SURFACES.

In last year's report, I described certain experiments by Dr. Nottingham having to do with the effect of an electric field in assisting the departure of electrons from metals under the influence of the photoelectric effect or the thermionic effect. For the significance of this matter and for the details concerning it, reference must be made to the previous report. The experiments involved heating a filament with a direct current and in connection with some of the finer points, the drop of potential produced by the heating current in the filament caused troublesome uncertainties in the matter of interpretation. For this reason, Dr. Nottingham turned to the well-known method of using an interrupted current, and making the measurements at those periods when the current was "off," but the temperature of the wire still persisted. The most efficient condition for such work is one where the current rises to a value which remains constant for a finite but short period and then suddenly drops to zero and remains there for an equal period, the whole cycle of events being repeated continuously hundreds of times per second. In other words, it is necessary to produce what is called an approximately square wave current. The reliability of the results is in proportion to the success in realizing the necessary features as regards this wave, and Dr. Nottingham has spent considerable effort in realizing these conditions in a satisfactory form. The investigation has involved the use of "General Electric Thyratrons" which are devices for controlling a large current through the influence of a small stimulus, and it has ramified into investigations on these appliances themselves, one of the most interesting conclusions being that these devices are extremely sensitive to temperature as regards their characteristics. Under certain circuit conditions, a change of 1° C. will cause a change in the current necessary for operation, amounting to a hundredfold or more. It is unnecessary to

[13] A detailed account was published in the *Physical Review*, 38, 473, 1931.

enter into detail on these matters now, as they have been described in Dr. Nottingham's publication on the subject.[14]

The net result of the improvements introduced by utilizing an interrupted heating current has been to confirm the results tentatively reached and reported upon last year, but with a much greater degree of certainty as to their reliability. The new technique also provides a means of more satisfactory extension of the investigations in fields of greater detail.

THE EFFECT OF TEMPERATURE ON THE CONTINUOUS BAND SPECTRUM OF MERCURY VAPOR.

I have at various times called your attention to the fact that an atom may be stimulated to emit radiation and that this excitation, as it is called, may be brought about either by the absorption of radiant energy or by impact of the atom with a swiftly moving electron. While the nature of the radiation with which we are ordinarily concerned in such cases is in the form of light of discrete wave-lengths or colors, under certain conditions, such as high pressures, a part of the emitted radiation may be distributed over a continuous range of wave-lengths. Such, for example, is the case with light emitted by mercury vapor, provided the pressure is high enough to make the average time between the collisions of an atom with the other atoms less than the time the atom stays in its excited state. Under such conditions, the emitted radiation, when spread out into a wave-length spectrum by the use of a spectrograph, is observed to consist of two continuous bands, each covering a wide range of wave-lengths, the one having a maximum intensity at 4850A°, the other with an intensity maximum at 3300A°. Dr. Nielsen has investigated the effect of temperature on the intensities of these two bands, and the results of his experiments, together with the results of other investigations concerned with mercury atoms have led him to a theory by means of which he can give a more accurate description of some of the characteristics of these atoms than was heretofore possible.

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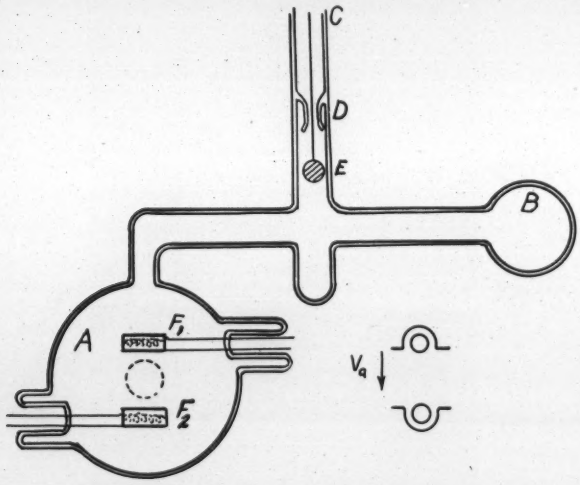
[14] Characteristics of Small Grid-Controlled Hot-Cathode Mercury Arcs or Thyratrons, JOURNAL OF THE FRANKLIN INSTITUTE, Vol. 211, pp. 271–301, 1931. Also, A Note on the Time Required to Set Up Conduction in an F.G. 17 Thyratron as Determined by a Study of a Linear Time Axis Circuit for an Oscillograph, JOURNAL OF THE FRANKLIN INSTITUTE, 211, 751, 1931.

The atoms which emitted the radiation observed in the work of Dr. Nielsen were excited by electron impact. A stream of electrons passed through the mercury vapor from the hot filament F_1, Fig. 26, towards a similarly formed but cold electrode F_2, acquiring energy along its path in consequence of a potential difference V_a between the two electrodes. The radiation emitted by the vapor in the region between F_1 and F_2 was photographed by means of a Hilger spectrograph through a quartz window, indicated by the dotted circle in Fig. 26, through which both the visible and the ultra-violet

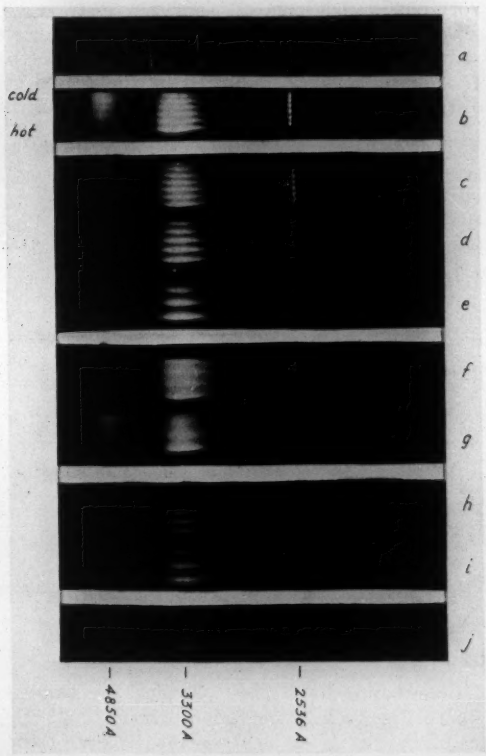
FIG. 26.



light of these bands could pass. Typical spectrograms obtained in this manner are reproduced in Fig. 27. Spectrogram (*a*) of Fig. 27 is an analysis into colors of the light from a mercury arc taken with low pressures of the vapor in the tube. The remaining spectra were obtained at higher pressures. In all cases the upper side corresponds to the cooler portion of the discharge space nearer F_2.

There are several distinctive features of these spectra which are useful in an understanding of the mechanism by which the observed ratiation is produced. One notices that

FIG. 27.



the radiation is confined to striations or limited regions in which alone the electrons are capable of stimulating radiation. Alternating with these are regions of darkness. In (*c*), (*d*),

and (*e*) of Fig. 27, the applied potential differences were 43, 33, and 23 volts respectively, while the corresponding number of the striations were 7, 5, and 3. The decrease in the number of striations for the given decreases in voltage is such as to lead to the conclusion that a difference in potential of approximately 5 volts exists between adjacent striations, for when the potential is reduced 10 volts two striations disappear. Now it is one of the characteristics of the impacts between electrons and atoms that at certain critical values of the energy of the electron, the collisions are perfectly inelastic and all of the energy of the electron is given up to the atom, later appearing in the form of radiation. The value 5 volts mentioned above as the difference in potential between adjacent striations corresponds quite closely to the known lowest energies which can be absorbed by the mercury atom, i.e., 4.86 and 4.66 volts respectively. Apparently, in the regions of the striations, practically all of the electrons suffer inelastic impact. After such collisions, the acceleration of electrons is repeated until they again acquire 5 volts of energy, which they give up once more in the adjacent striation by another inelastic impact.

The second distinctive feature of the observed spectra is the complementary variation in intensity of the two bands at 4850A° and 3300A°. In the region of the hot filament, the 3300A° band is relatively intense, whereas the 4850A° band is very weak if at all detectable. Near the cold electrode, on the other hand, the 4850A° band is intense, and the 3300A° band is fainter than in the hot part of the tube. Apparently, these intensity variations depended upon the temperature of the vapor, but to make doubly sure of this effect, the lower electrode F_2 was heated to a temperature considerably higher than the temperature of F_1. The 4850A° band shown in (*f*) of Fig. 27 was now entirely destroyed, and the 3300A° band was considerably enhanced as compared with the case reproduced for comparison in (g), in which the lower filament was not heated. The relative intensities of the two bands are, therefore, definitely a function of the temperature.

As a first step in the explanation of the phenomenon, we must suppose that one band is emitted by one type of entity and the other by another type, and that the ratio of abun-

dance of the two entities varies with the temperature. The fact that the radiation emitted is of the nature of a continuous band instead of a line spectrum as in (*a*) leads to the next step in the explanation that both types of entities involved are molecules composed of two or more atoms and are not single atoms of mercury. This second postulate is in harmony with the first, for if there are two types of molecules having different energies of formation it is to be expected that their relative abundance will vary with the temperature. For some time, physicists have thought that mercury molecules could be formed by the union of one unexcited atom and one atom in an excited state of higher energy, and Dr. Nielsen believes that the radiation which he has observed in these bands is given off by molecules which have been formed in this manner. The experiments show, first, that there must be two different energy states of these molecules and, second, that the molecules are very unstable, for they break down and give off radiant energy before they drift out of the narrow regions where they are formed. Since the light which they emit in their disintegration is of the nature of a continuous band of wave-lengths or, corresponding to photons which are ejected with varying amounts of energy, it is necessary to suppose that only a part of the energy of the molecule goes into the photons and that the remainder goes into the kinetic energy of the atoms as they fly apart again.

The wave-lengths of the two bands and the potential differences between striations are such as to suggest that the two types of molecules which we have supposed to be involved in the phenomenon are made up of normal atoms combined with atoms in the two lowest states of excitation, and that after the radiation has taken place the atoms are again in their normal, unexcited states. Assuming this to be the case, Dr. Nielsen has calculated the relative abundance of the two types of molecules at temperatures which could reasonably be supposed to exist in the various parts of the space between the electrodes, and the results which he obtained are in good agreement with the intensity variations which he observed.[15]

[15] The complete account of this work appeared in the *Physical Review*, **38**, 888, 1931.

Mr. President, Members of the Institute, the laboratory, is a large atom and as a result of the activities of external agencies and of some self-excitement, its individual entities are continually being put into excited states. I will not say that in these states they are to be characterized by mean lives, but I will say that the only way of departing from these states is by the emission of something. Sometimes the atom emits radiation in the form associated with heat, and possibly some of the emissions from the entities of the laboratory may be in the form of hot air. However, we endeavor to keep the amount of this kind of radiation down to the minimum associated with any natural source of radiation which is responsible for the emission of light in an appreciable amount.

NOTE: Figures 10, 11, 12, 20, 21, 22, 26 and 27 appeared in the *Physical Review*, volumes 37 and 38, and are reproduced by the courtesy of Dr. John T. Tate, Managing Editor.

Nickel in Hotel Construction. Four carloads of nickel, in the form of alloys, have gone into the new Waldorf-Astoria Hotel in New York City. The total—142,500 pounds—represents the biggest single installation of nickel in building construction in the United States this year.

Almost 175,000 pounds of monel metal, which contains two-thirds nickel and one-third copper, have been used for kitchen equipment and for other service uses.

Fully 105,000 pounds of 20 per cent. nickel-silver have been used for plumbing fixtures, and an additional 45,000 pounds of 10 per cent. nickel-silver have been used for decorative trim. The heroic figure, "The Spirit of Achievement," which adorns the main portal, contains nickel. The statue is made of 8 per cent. nickel bronze and weighs 420 pounds.

R.

Molecular Weight of Insulin. BERTEL SJÖGREN AND THE SVEDBERG of the University of Upsala. (*J. Am. Chem. Soc.*, 1931, *53*, 2657–2661) find that insulin has a molecular weight of 35100, and is stable within the pH range 4.5 to 7.0. It apparently is a well-defined protein; and its physiological activity is due either to the molecule as a whole, or to some special group within it.

J. S. H.

PAINTS FOR REFLECTING BIOLOGICALLY-IMPORTANT ULTRAVIOLET RADIATION.

BY

M. LUCKIESH and L. L. HOLLADAY,

Lighting Research Laboratory,
General Electric Company,
Nela Park, Cleveland.

For years the reflectances of white paints for ceilings and of materials used in lighting equipment have been improved through lighting development. Similarly, in the extension of artificial lighting to include ultraviolet radiation for health as well as light for seeing, the reflection of ultraviolet radiation of certain wave-lengths becomes an important matter.[1] In special equipment, such as for therapeutic practice, there is no urgent need for a variety of efficient ultraviolet-reflecting surfaces. A few materials, such as aluminum and chromium, fill the needs fairly well. In so-called dual-purpose lighting, in which an ultraviolet component is included, the reflectances of various media must be known and improved, if possible, to meet economic requirements. Already oxidized aluminum has been greatly improved [2] as a reflector of ultraviolet radiation of known biological importance. Various materials have been studied for years [3] and from these we have been able to produce paints and other media of appreciably greater reflectances in the ultraviolet region.

In the general use of so-called artificial sunlight we are particularly concerned with ultraviolet radiation between λ2800 and λ3100 or perhaps λ3200. The limit of the solar spectrum ends at about λ2900 and this would be the ideal limit for artificial sunlight. Inasmuch as the spectral transmission of a filter does not end abruptly, it is more practicable and apparently quite safe to establish the short-wave limit of artificial sunlight for general use at λ2800. Ordinary glass does not transmit ultraviolet radiation of known importance to human beings, so that the long-wave limit of biological importance may be taken as λ3100 or λ3200. In the measurements recorded herewith the instrument possessed sensibility between λ2800 and λ3200 with a maximum near the mercury lines

λ2967 and λ3024. In fact, the integral reflectances for the range, λ2800 to λ3200, correspond fairly well with the reflectances for λ3024.

Data are presented for various pigments, commercial paints and wall-papers, and representative mixtures of materials which we have made for the purpose of developing efficient ultraviolet-reflecting media for ceilings and other areas in the practice of so-called dual-purpose lighting as well as radiation therapy on a large scale. With the exception of certain metals, white pigments are of chief importance where visible radiation as well as ultraviolet radiation must be reflected efficiently. Of course, there are special cases where the visible radiation is of no importance, but these are not considered here.

MEASUREMENT OF REFLECTANCE.

Measurements of the reflectances of various commercial paints and wall-papers for ultraviolet radiation of biological importance were made by comparing the amounts of radiation reflected from the paint or paper with that reflected from magnesium carbonate. The amount of reflected radiation in each case was measured with a fluorescent photometer,[4] sensitive to radiations chiefly in the region between λ2800 and λ3200. These values of reflectances relative to magnesium carbonate were then reduced to absolute reflectances by multiplying the observed values of relative reflectances by the absolute reflectance of the specimen of magnesium carbonate. The reflectance of the specimen of magnesium carbonate, with which the reflectances of the various paints and papers were compared, was about 0.68 for the biologically-effective radiation measured by the fluorescent photometer.

The sources of ultraviolet radiation were a quartz mercury arc and a Mazda Sunlight lamp (Type S-1).

The reflectances of the metallic paints and wall-papers, which were highly specular in reflecting characteristic, were corrected by measurements made with a special spherical photometer.

WALL-PAPERS.

Seventy specimens of commercial wall-papers were studied. With the exception of the metallic ones, employing aluminum foil or paint, the reflectances for biologically-

important ultraviolet radiation generally ranged from 0.10 to 0.25. Samples of aluminum wall-paper were found to have reflectances from 0.68 to 0.82. White wall-papers with some of the area covered with flecks or conventional designs of aluminum yielded reflectances of 0.25 to 0.34 and the so-called sanitary papers, 0.10 to 0.20.

WHITE PIGMENTS.

These are readily divided into two groups. Among those which poorly reflect the biologically-important ultraviolet radiation are zinc oxide, titanium pigment, lithopone, and tin oxide. Pigments which fairly well reflect ultraviolet radiation of the desired wave-lengths are magnesium oxide, magnesium carbonate, calcium carbonate, silica, asbestine, and china clay. Some of these are lacking in body. Lead carbonate or white lead, commonly used in paint, moderately reflects the desired ultraviolet radiation. Of course, the vehicle in which pigments are suspended is very important. Some vehicles commonly used are not satisfactory although, if used sparingly, some may be fairly satisfactory.

In Table I is presented a summary of common white

TABLE I.

Reflectances of White Powders for Light and for Biologically-Important Ultraviolet Radiation.

	Reflectances.	
	Visible.	Ultraviolet.
Aluminum oxide	0.94	0.74
Asbestine	.95	.60
Basic carbonate	.95	.64
Barium sulphate	.93	.60
Calcium carbonate	.92	.83
China clay, Kaolin	.85	.50
Hydrated lime	.73	.48
Lithopone	.92	.04
Lamp black	.04	.04
Magnesium carbonate	.98	.68
Magnesium oxide	.98	.95
Silica	.96	.55
Sublimed white lead	.88	.50
Tin oxide	.90	.04
Titanium pigment	.90	.04
Whiting	.92	.63
Zinc oxide	.90	.02
Zinc sulphate	.97	.01

materials [3] which may or may not be used as pigments in paints for dual-purpose lighting.

COMMERCIAL PAINTS.

Common white paints known as egg-shell gloss, flat white and white Duco exhibited reflectances of only 0.08 for the biologically-important ultraviolet radiation. The low reflectances of these are chiefly due to the absorption of the pigments. The reflectance of white lead in linseed oil was 0.30. Of course, the binder becomes important when the reflectance of the pigment is high. Inasmuch as most binders, commonly used, are not very transparent to the desired ultraviolet radiation, they should be used sparingly.

The influence of the binder is well illustrated by the metallic aluminum paints. For example, clean aluminum may reflect 75 per cent. of the desired ultraviolet radiation. This may be greatly reduced by the binder and the manner of application, such as brushing or spraying. Reflectances of aluminum paints varied from 0.40 to 0.68.

Cold-water paints should have generally greater possibilities in reflecting ultraviolet radiation efficiently, owing to the absence of heavy binders such as linseed oil. Binding media are used sparingly. Many specimens of cold-water paints were studied. These included such commercial products as Kalsomine, Kalkomo, Calsom Finish and Decotint. The reflectances for the desired ultraviolet radiation ranged from 0.25 to 0.40 per cent. White cement exhibited a reflectance of 0.22.

SPECIAL ULTRAVIOLET-REFLECTING PAINTS.

In this study we were not primarily concerned with cost or even with practicability from the viewpoint of the manufacturer. Our purpose in making and testing many mixtures was a preliminary survey of the possibilities. However, the mixtures were examined for applicability, resistance to moisture and water, smoothness, strength, cracking, porosity and deterioration under exposure to ultraviolet radiation. Results are presented for some mixtures which seemed to us promising as paints for interior use in connection with solariums and dual-purpose lighting.

Cold-Water Paints.

Very satisfactory cold water paints were made with casein as a binder and one or more of the white pigments that have high reflectances in the biologically-important ultraviolet region between λ2800 and λ3200. A water resistant or washable cold-water paint requires that the binder readily dissolve in cold water while mixing, but becomes insoluble on drying. Casein is normally insoluble in water, but by the addition of hydrated lime or other alkali it becomes readily soluble in water. When hydrated lime is used, an insoluble calcium caseinate is formed on drying. Care must be used in the use of hydrated lime, formalin or other insolubilizer, if satisfactory results are to be obtained. If too little lime is used an insufficient amount of calcium caseinate will be formed to render the paint waterproof and if too much is used the paint may become a glutinous mass or the paint may become brittle and crack. China clay seems to make the paint brush easier; gum arabic tends to prevent the paint settling; and borax and sodium benzoate help to preserve the paint. Starch seems to make the paint weak and porous and dextrine seems to absorb the ultraviolet radiation. Sodium silicate, when used in large quantities, seems to decrease somewhat the ultraviolet reflectance of the paint and would have a tendency to make the paint bloom. The composition of various successful mixtures of cold-water paints, containing casein, are presented in Table II. The reflectance of each special paint for ultraviolet radiation of biological importance is presented in the last horizontal line of the table.

The pigment was ground to a fine powder. The hydrated lime and other alkalies were dissolved in one container; and the casein was put in another container with a little water and allowed to soak for about ten minutes. Then the casein and half the alkaline solution were mixed and the casein was allowed to dissolve. When the casein was fairly well dissolved it was strained through a cheese cloth to remove the undissolved particles. The pigments were mixed in a separate container and sufficient water was added to make a stiff paste. The gum arabic was dissolved in a separate container. The solutions of casein, gum arabic and remaining alkalies were

TABLE II.

Compositions in Parts by Weight Per Hundred of a Number of Specially Prepared Cold-Water Paints and Their Reflectances of Biologically-Important Ultraviolet Radiation.

Paint	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*J*
Magnesium oxide	..	..	..	16	47	..	..	..	..	34
Magnesium carbonate	36	37	33	16	..	40	35	35	37	..
Aluminum oxide	15	..	..	15	..	..	..	..	..	14
Silica	..	..	19	..	..	..	19	19	21	..
Calcium carbonate	14	36	15	15	15	20	15	15	17	13
China clay	..	..	9	8	8	10	..	..	..	..
Asbestine	11	9	..	..	..	..	..	..	..	10
Casein	15	..	15	15	15	14	16	16	16	14
Gum arabic	2	18	2	..	2	2	2	2	2	2
Sodium silicate	..	..	..	..	..	4	..	8	..	..
Hydrated lime	4	..	4	11	11	9	12	4	4	12
Borax	1	..	1	2	..	1	1	1	1	1
Sodium bicarbonate	2	..	2	..	..	..	..	..	2	..
Formaldehyde	..	0.1	..	..	..	..	..	..	..	..
Dextrine	..	..	..	2	..	..	..	..	..	..
Sodium benzoate	..	..	..	..	2	..	..	..	..	..
Reflectance	0.54	0.54	0.54	0.43	0.48	0.54	0.40	0.47	0.50	0.53

mixed with the pigment paste and sufficient water was added (if necessary) to make a creamy paint.

Hot-Water Paints.

By the use of glue as a binder a few hot-water paints were made which were found to reflect not more than two-thirds as much of the biologically-important ultraviolet radiation as the cold-water paints. These paints contained one or more of the white pigments having high spectral reflectances in the important ultraviolet region. Hot water is required to dissolve the glue and heat is required to keep the paint in good working condition while applying. The composition and ultraviolet reflectance of each of these paints is presented in Table III.

TABLE III.

Compositions of Various Special Hot-Water Paints and Their Reflectances for Biologically-Important Ultraviolet Radiation.

Paint.	*K*	*L*	*M*	*N*	*O*	*P*
Magnesium oxide	..	..	..	..	..	39
Magnesium carbonate	..	34	34	23	27	..
Aluminum oxide	..	..	..	22	26	..
Silica	..	..	..	11	27	39
Calcium carbonate	75	35	34	..	..	..
China clay	13	..	..	17	7	..
Asbestine	..	9	9	..	..	2
Glue	12	17	17	22	13	20
Gum arabic	..	4	4	..	..	..
Formaldehyde	..	0.7	..	1.1	..	..
Trisodium phosphate	..	..	2	1.4	..	..
Sodium chloride	..	..	..	2.5	..	..
Reflectance	0.27	0.30	0.33	0.29	0.29	0.27

Linseed-Oil Paints.

White lead and linseed oil make paints that reflect at most not more than about one-third of the biologically-important ultraviolet radiation. Linseed oil in combination with other white pigments of higher reflectances than white lead did not result in a paint of greater ultraviolet reflectance than white lead and linseed oil. This may be seen by reference to Table IV.

TABLE IV.

Compositions of Various Special Linseed-Oil Paints and Their Reflectances for Biologically-Important Ultraviolet Radiation.

Paint.	*Q*	*R*	*S*	*T*	*U*	*V*
Magnesium oxide	..	..	..	13	..	8
Magnesium carbonate	19	17	..	..	13	9
Calcium carbonate	..	4	..	..	5	4
Lead carbonate	18	..	50	13	..	..
China clay	..	2	..	3	5	..
Linseed oil	42	12	33	13	9	9
Turpentine	21	..	17	58	68	70
Amyl acetate	..	65	..	..	..	..
Reflectance	0.17	0.30	0.32	0.21	0.27	0.29

Nitrocellulose Lacquer Paints.

Nitrocellulose lacquer appears to be one of the best binders for a paint which is to reflect the biologically-important ultra-

violet radiation. It appears to be well to use a minimum of lacquer and a maximum of a thinner, such as amyl acetate. With mixtures of the proportions given in Table V it is easy to make paints with reflectances of 0.50 to 0.60 for the desired ultraviolet radiation.

TABLE V.

Compositions of Various Special Nitrocellulose Lacquer Paints and Their Reflectances of Biologically-Important Ultraviolet Radiation.

Paint	*W*	*X*	*Y*	*Z*	*AA*	*BB*	*CC*
Magnesium oxide	..	14	14	..	..	17	16
Magnesium carbonate	14	..	..	34	..	..	..
Aluminum oxide	..	..	..	..	23	..	..
China clay	..	..	..	..	6	..	4
Nitrocellulose lacquer	29	29	29	33	24	12	8
Lacquer thinner	..	..	29	33	47	..	72
Amyl acetate	57	57	28	..	..	71	..
Reflectance	0.51	0.44	0.51	0.48	0.40	0.51	0.58

CONCLUSIONS.

It appears that the ordinary brands of glue, linseed oil, and varnishes, such as were used in these experiments, are not very well suited for binders and vehicles in making ultraviolet-reflecting paints. On the other hand, with either casein or nitrocellulose lacquer very good paints should be made which reflect from 0.55 to 0.65 of the biologically-important ultraviolet radiation. A large proportion of magnesium oxide, magnesium carbonate, aluminum oxide, or a combination of them appears necessary to produce a paint having a high ultraviolet reflectance. However, moderate amounts of silica, calcium carbonate, china clay and asbestine may be used without materially reducing its reflectance to ultraviolet radiation.

As stated in the beginning, these experiments are in no sense considered final for the paint manufacturer. The paints were prepared from the viewpoint of physicists possessing data pertaining to reflectance of biologically-important ultraviolet radiation and knowing the need for paints and other media for artificial sunlighting and dual-purpose lighting. The results should be helpful to the manufacturer of paints and to anyone interested in reflecting ultraviolet radiation between λ2800

and λ3200. In fact, anyone may readily make special paints for this purpose quite satisfactorily from the foregoing summary of the work done.

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3. *Spectral Reflectances of Common Materials in the Ultraviolet Region*, by M. Luckiesh, Jour. Opt. Soc., 19, 1929, 1.
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Airway Maps. (U. S. Coast and Geodetic Survey, 100th Annual Report.) The comparatively new mode of travel by air is growing daily. It is therefore unnecessary to emphasize the dollars-and-cents value in safety of airway maps. They are as essential as the nautical chart and every other safety aid, whether they be for transportation over land or sea.

Strips maps, limited to the terrain along established airways, were found unsatisfactory with most of the flying off the commercial lanes. To accommodate the new needs, the Coast and Geodetic Survey has undertaken a new series to consist of 92 sectional airway maps eventually to cover the entire United States. Three have already been issued, lithographed in colors on bond paper to permit folding.

R.

Tide Studies. (U. S. Coast and Geodetic Survey, 100th Annual Report.) Primary tide stations of the Coast and Geodetic Survey furnish the basic data for the intelligent execution of engineering works along the coast. Their fundamental importance is becoming more recognized.

As tides are caused by the attractive force of the moon and the sun, the layman, and indeed many engineers, think of the tide as a universal unvarying world phenomenon. Having once ascertained the ocean tide, its future daily occurrence is predicted with certainty.

Regional differences are the result of terrestrial rather than astronomical features. Changes in the dimensions of an entrance and dredging or filling in an interior basin may result in material tidal changes. In view of the rapid economic development our shores are undergoing, there is need for a proper advance realization by the developers of the probable effect of contemplated projects, for their accurate appraisal. The solution of each problem, however local, contributes in the aggregate to scientific and engineering knowledge of value to every section.

R.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

VAPOR LOCK IN AUTOMOBILE FUEL SYSTEMS.

A report on vapor lock in automobile fuel systems was presented by O. C. Bridgeman at the meeting of the American Petroleum Institute on November 10.

During the past summer a survey has been made at the bureau of the gasoline temperatures in the fuel feed systems of this year's automobiles, in coöperation with the Society of Automotive Engineers, the National Automobile Chamber of Commerce, and the American Petroleum Institute. Road tests at various speeds were made on 47 out of the 65 distinct models of 1931 cars on the market. These cars were made available to the bureau through the courtesy and coöperation of the local dealers in Washington. It was found that in many of these cars sufficient precautions had not been taken by the manufacturer to prevent heat from the engine warming the gasoline in the fuel lines. Since excessive heating causes the gasoline to boil, which results in vapor lock and stalling of the engine, the remedy for this difficulty lies in designing cooler fuel systems. The information obtained in this survey has been made available to the individual car manufacturers, and there are indications that fuel systems in the 1932 cars will be much cooler.

The road tests also gave information on the vapor pressure of the gasoline which can be used without boiling of the gasoline. If a gasoline has a high vapor pressure, it boils readily, so if the refiner controls the vapor pressure of the gasoline, he can keep trouble from boiling to a minimum. The work of the bureau on 1931 cars tells how low the vapor pressure must be for satisfactory operation with these models. Of course, the vapor pressure cannot be made too low, otherwise there will be difficulty with engine starting in cold weather.

The automotive and petroleum industries are coöperating in solving the problem of engine stoppage as the result of

*Communicated by the Director.

boiling gasoline. The automotive engineer is attempting to keep the fuel lines cool; the petroleum refiner is controlling the vapor pressure of his product. The results of this coöperation will become more and more evident to the motoring public during the coming year or two, until vapor lock as a cause for engine stoppage will become a thing of the past.

AUTOMATIC RECORDER FOR HEIGHT OF KENNELLY-HEAVISIDE LAYER.

During the last few years measurements of the virtual height of the Kennelly-Heaviside layer (the layer of ionized air at a height of 100 miles or more above the surface of the earth) have commanded no little interest and numerous papers have been published describing such observations. In America most of the workers have employed the group retardation or pulse method originated by Breit and Tuve. This method employs a radio transmitter which sends out pulses of perhaps two ten-thousandths of a second duration at the rate of about 30 pulses per second. These pulses may arrive at the receiving station by paths through the upper atmosphere (i.e., the Kennelly-Heaviside layer) as well as along the surface of the earth. In practice these pulses are received, amplified, and then recorded photographically by means of a string oscillograph. For each transmitted pulse the oscillograph pattern will show a sharp peak rising from the base line for the impulse which has arrived at the receiving station by the ground path, and slightly displaced from this peak may appear one or more other peaks representing impulses which have been reflected or refracted from the upper atmosphere. If the time interval between the arrival of the ground and reflected impulses is measured, the virtual height may be computed. The major difficulty with this method is that each oscillogram taken gives the virtual height only over a brief period, usually a fraction of a second. It is evident, therefore, that the development of some automatic device giving a height record is of major importance to any program which contemplates continuous measurements of layer height.

A method which has been developed by the bureau is similar to that described above except that a few modifications

are necessary. The essential requirement is that the "chopper" which makes the pulses at the transmitter and a revolving mirror in the oscillograph at the receiving station both be driven by synchronous motors connected to the same power system. If this requirement is fulfilled then the pulse patterns may be viewed on a screen in the manner commonly used for viewing recurring phenomena with the oscillograph. If a mask with a slit is placed over the pattern so that the slit is parallel to, and slightly above the base line of the peaks, and if the film is caused to move slowly across the pattern in a direction perpendicular to the slit, then traces will be registered on the film for each of the peaks. The trace made by the ground pulse should be a straight line because the length of the path between transmitter and receiver for this pulse remains unchanged. However, as the Kennelly-Heaviside layer changes in height the path length for the other impulses will change and the corresponding traces will shift in position on the film with respect to the ground trace. The distance on the film from any trace to the ground trace will be a measure of the virtual height for the corresponding reflection.

A report in the November number of the *Bureau of Standards Journal of Research* describes a preliminary set-up which has proven the practicability of such an arrangement for making continuous height records, and improvements are suggested which might be incorporated in a permanent installation.

THREADLOCKING DEVICES.

An investigation has been completed by the bureau to determine the torque required to unscrew nuts with and without locking features, under static loads, and, also, to determine the torques required to produce a given stress in the bolt. All known manufacturers of threadlocking devices were invited to participate in the investigation; of these twenty-four accepted the invitation. Each manufacturer submitted 100 samples of his device to fit bolts having a diameter of three-quarters inch. Forty-one devices were tested, including standard nuts, jam nuts, and slotted nuts with cotter pins. A report of the work will be published in the November number of the *Bureau of Standards Journal of Research.*

For each device curves were plotted showing: 1, the relation between the torque on the nut, when it was tightened and the tensile stress in the bolt; 2, the relation between the torque on the nut, when it was unscrewed, and the stress in the bolt.

These curves show that only about one-quarter of the devices had appreciably different static torque-tension relations from those of the American National coarse thread nut; and for only one device was the screwing-off torque greater than the screwing-on torque for each stress. Other things being equal, a locking device requiring a high torque to unscrew it would be expected to prove more satisfactory in service than one requiring a low torque.

Methods of testing these devices under other conditions, particularly those simulating service, are being studied and reports on these tests will be published when satisfactory results are obtained.

IMPROVED LABORATORY RECTIFYING STILLS.

The November number of the Bureau of Standards Journal of Research will contain a complete description of a set of all-glass rectifying stills, suitable for distillation at pressures ranging from atmospheric down to about 50 mm. The stills are provided with efficient bubbling-cap columns containing 30 to 60 plates. Adiabatic conditions around the column are maintained by surrounding it with a jacket provided with a series of independent electrical heating units. Suitable means are provided for adjusting or maintaining the reflux ratio at the top of the column. For the purpose of conveniently obtaining an accurate value of the true boiling points of the distillates a continuous boiling-point apparatus is incorporated in the receiving system. An efficient still of the packed-column type for distillations under pressures less than 50 mm. is also described.

Methods of operation and efficiency tests are given for the stills.

PURITY OF MERCURY.

In the development of a specification for mercury suitable for use in the making of dental amalgams the effect of base metal impurities on the properties of mercury was observed.

The presence of only 0.001 per cent. of such metals as zinc, tin, lead, cadmium, bismuth, copper, magnesium, or antimony so changed the appearance of the mercury that anyone observing the metal would believe it to be badly contaminated. The changed properties of mercury caused by base metal contamination have been recorded before, but the fact that the appearance of the mercury may be used as a test for base metal contamination has never been emphasized.

Contamination of mercury with silver or gold could not be detected by the changed appearance of the mercury. When either of these metals was present to the extent of 0.1 per cent. there still was no marked change in the appearance of the mercury.

These observations indicate that mercury that is clean and bright and has the characteristic property of not wetting a glass surface cannot contain more than very minute amounts of base metal.

PRESERVATION OF RECORDS.

A summary of the progress made at the bureau in studies of the preservation of written and printed records is contained in a report recently issued by the bureau.

Thorough tests of the relative permanence of the current commercial writing and printing papers have been completed. The tests indicate there are papers made from both rag and wood fibers that are suitable for any required degree of permanence, providing the papers are stored under favorable conditions. A suggested classification of papers relative to the varying degrees of permanence required, graded them according to their degree of cellulosic and non-cellulosic purity as this is apparently the significant factor in respect to deterioration.

Tests have been made also of over a thousand old publications that have been stored in public libraries for varying periods during the past one hundred years. These tests like those of the current papers reveal the importance of fiber purity. Papers containing crude fibers such as ground wood and unbleached fibers were generally brittle and yellow while those containing fibers well purified by chemical treatment, were generally in good condition.

The results of a survey of public libraries and similar depositories in various regions of the United States indicated the chief external deteriorating influences to be acid pollution of the atmosphere, particularly sulphur gases from combustion of fuels, high temperatures, variations in atmospheric humidity, light, and dust. Laboratory studies of these influences have been initiated. Exposure of papers to an atmosphere containing sulphurdioxide has shown this combustion gas to be a very potent deteriorating agent. Exposure to light of the rosin sizing materials used for paper discolored them, which is further evidence that they are one cause of discoloration of paper.

The report was published in the October issue of *The Library Quarterly* and reprints of it are available at the bureau.

REINFORCED BRICKWORK.

In coöperation with the Common Brick Manufacturers Association 18 beams of reinforced brickwork were tested to determine the resistance of the brickwork to diagonal tensile stresses. The investigation was limited to a study of the effect of the arrangement or bonding of the bricks.

The beams were 14 feet long and about one foot square in cross section. Nine of the beams were built with common brick from Chicago and the other nine with common brick from Philadelphia. In one type of beam the bricks were laid in common American bond as in a 12-1/2 inch wall; in another the bonding was similar to that in a lintel beam with a soldier course forming the lower portion of each face of the beam, over which were laid two stretcher courses. The third type was built on end with vertical reinforcements to resemble a portion of a 12-1/2 inch retaining wall with all bricks laid as stretchers. A 1 : 3 Portland cement-sand mortar, with an addition of lime equal to 15 per cent. of the volume of the cement, was used for all beams. Each beam contained six 1/2-inch square bars as tensile reinforcement.

A load test was made by supporting the beam on a span of 12 feet and applying equal loads at the quarter points of the span. First the load was increased by small increments until the deformations indicated that the maximum stress in

the steel was at least 15,000 lbs./in.^{2} Then the load was reduced to a total of 1,000 lbs. and finally increased by small increments until failure occurred. The set remaining after the first loading was roughly one-fifth of the maximum deformations before reducing the load, which is of the same order of magnitude as has been observed with reinforced concrete beams of about the same initial stiffness.

Cracks which tended to follow diagonal planes between the contacts with the beams of the supports and the nearer loads, formed before the failures of the beams took place. In some instances they passed through the bricks, their locations apparently being unaffected by the mortar joints; while in others, the mortar joints were opened along an irregular line extending from a support toward the nearer load. The maximum shearing stresses ranged from 60 to 160 lbs./in.,^{2} the values depending chiefly upon the kind of brick and their bonding in the beams.

Tests are now under way to determine the strength of the bond between mortar and bricks similar to those used in the beams.

Hydrographic Surveys of Water Areas. (U. S. Coast and Geodetic Survey, 100th Annual Report.) The report states that the postwar period has witnessed revolutionary changes in the method of making a hydrographic survey of water areas—the principal step in the processes of chart production.

The application of recent innovations based on the utilization of the velocity of sound in sea water permits a surveying vessel while traveling at full speed to gather a continuous profile of the bottom. Visibility of land or weather conditions are non-essentials. The rate of progress is multiplied and permits the definite completion of projects formerly expected to extend into the indefinite future.

The two principal operations in the survey of a water area combine the measurement of thousands of water depths and the determination of their positions on the earth's surface.

Depths are measured by accurately ascertaining the time for a sound at the ship's hull to travel to the bottom and reflect back. The location at which the depth is measured is learned in a similar manner. The sound of a bomb exploded in the water near the ship, radiating in the water in all directions, is picked up by microphones at two shore stations of known positions. The minute impulse is automatically magnified and radioed back to the ship. There its receipt is recorded by the same delicate instrument which previously recorded the time of the explosion.

The travel of the radio wave is practically instantaneous. Consequently, the elapsed times are those required for the sound to travel from the bomb to the respective microphones. The results obtained are two distances from the ship to two known points at the shore, and in consequence the position of the vessel.

R.

THE FRANKLIN INSTITUTE.

STATED MONTHLY MEETING, NOVEMBER 18, 1931.

The regular monthly meeting of The Franklin Institute was called to order at eight-sixteen P.M. by Vice-President Walton Forstall, who presided.

The Chairman announced that the minutes of the October meeting had been printed in full in the JOURNAL of the Institute and that unless objection were offered the minutes would be approved as printed. No objection was offered and the minutes were declared approved.

The Chairman called upon the Secretary for any business. The latter stated that there was no business to present but that he had one notice to read. He then spoke of the Christmas Week Lectures for the coming Christmas season and announced that the lecturer would be Dr. Dayton Clarence Miller of the Case School of Applied Science, one of the leading lecturers of the United States and one of the outstanding authorities in the field of sound in the world. Dr. Miller's lectures are to be devoted to that branch of physics.

The Chairman of the evening then requested Mr. Walter R. Russell of the Board of Directors of City Trusts to assume charge of the meeting and to proceed with the presentation to Professor Philip Drinker and Mr. Louis A. Shaw of John Scott Medals and Premiums, for their invention of apparatus for administration of artificial respiration. These two gentleman had requested that the medals might be presented them before The Franklin Institute.

After the conclusion of these exercises the Chairman, Mr. Forstall, again resumed control of the meeting and introduced as the lecturer of the evening Professor Philip Drinker, who spoke on "Prolonged Administration of Artificial Respiration." The talk of the evening was followed by an interesting demonstration of the respirator by a man and a woman and was also followed by a considerable amount of discussion.

The meeting adjourned with a rising vote of thanks to the inventors, at nine-fifty P.M. The lecture and the demonstration were among the most interesting exercises held at the Institute in recent months.

HOWARD MCCLENAHAN,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(*Abstract of Proceedings of Stated Meeting held Wednesday, November 11, 1931.*)

HALL OF THE COMMITTEE,
PHILADELPHIA, NOVEMBER 11, 1931.

MR. LIONEL F. LEVY *in the Chair.*

The following report was presented for first reading:

No. 2930: Teleseismograph.

The Eclipse Projector, which will be a part of the equipment used by the Astronomical Department of the Institute's Museum, was demonstrated by Mr. James Stokley.

GEO. A. HOADLEY,
Secretary.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(*Stated Meeting, Board of Managers, November 18, 1931.*)

RESIDENT.

MR. GUSTAVUS WYNNE COOK, Manufacturer and Banker, Wynnewood, Pennsylvania.

STUDENT.

MR. CYRUS BECK, Student, Temple University. For Mailing: 1000 North Forty-fifth Street, Philadelphia, Pennsylvania.

CHANGES OF ADDRESS.

DR. BYRON E. ELDRED, 225 East Seventy-third Street, New York City.
MR. HENRY G. HART, 231 East Sixtieth Street, New York City.
MR. MALCOLM LLOYD HAYWARD, Milton Academy, Milton, Massachusetts.
W. J. JEFFRIES, ESQ., 8134 Arlington Avenue, Highland Park, Delaware County, Pennsylvania.
MR. NATHAN M. LOWER, 2200 Garrison Boulevard, Baltimore, Maryland.
DR. WALTER M. MITCHELL, 112 North Thirty-fourth Street, Philadelphia, Pennsylvania.
DR. STUART MUDD, 734 Millbrook Avenue, Haverford, Pennsylvania.
MR. C. E. POSTLETHWAITE, 142 Hamilton Avenue, New Rochelle, New York.
MR. IRVING B. SMITH, 1704 Hillcrest Road, East Chestnut Hill, Pennsylvania.
MR. F. W. SPERR, JR., 5 North Oxford Street, Ventnor, New Jersey.
MR. HARRY R. VAN DEVENTER, 3 West Fiftieth Street, New York City.
MR. JOHN S. WILSON, 58 Simpson Avenue, c/o J. J. Bryan, Esq., Pitman, New Jersey.
PROF. GEORGE WINCHESTER, Rutgers University, New Brunswick, New Jersey.
MR. CHARLES S. WURTS, JR., 1327 Walnut Street, Philadelphia, Pennsylvania.

NECROLOGY.

Mr. Henry M. Justi, Philadelphia, Pennsylvania.

LIBRARY NOTES.

RECENT ADDITIONS.

Academy of Motion Picture Arts and Sciences. Recording Sound for Motion Pictures. Edited by Lester Cowan. 1931

American Foundrymen's Association. Transactions. Volume 38, 1931.

American Institute of Electrical Engineers. Transactions, Volume 50, Number 3, September, 1931.

Association of Official Agricultural Chemists. Official and Tentative Methods of Analysis. Third edition. 1930.

BAEDEKER, KARL. Berlin and Its Environs. Sixth edition. 1923.

BAEDEKER, KARL. Northern Germany, Excluding the Rhineland. Seventeenth revised edition. 1925.

BAEDEKER, KARL. Paris and Its Environs, with Routes from London to Paris. Eighteenth revised edition. 1913.

BAINBRIDGE AND MENZIES' Essentials of Physiology. Seventh edition, edited and revised by H. Hartridge. 1931.

BARNES, RALPH, M. Industrial Engineering and Management: Problems and Policies. 1931.

British Association for the Advancement of Science. The Advancement of Science, 1931. Addresses Delivered at the Centenary Meeting. 1931.

British Association for the Advancement of Science. London and the Advancement of Science, by various authors. 1931.

CROSS, ROY. A Handbook of Petroleum, Asphalt and Natural Gas. 1931.

DURRANS, THOS. H. Solvents, Second and revised edition. 1931.

EDMONDS, FRANKLIN SPENCER. History of the Central High School of Philadelphia. 1902.

Electrochemical Society. Transactions, Volume 59. 1931.

FELIX, EDGAR H. Television: Its Methods and Uses. 1931.

FINDLAY, ALEXANDER. Practical Physical Chemistry. Fifth edition. 1931.

Forschungsinstitut der Čechoslovakischen Zuckerindustrie in Prag. Bericht für das Jahr 1930–31. Band 34. 1931.

GHIRARDI, ALFRED A. Radio Physics Course: an Elementary Radio Text Book. 1930.

HARRISON, A. W. C. The Manufacture of Lakes and Precipitated Pigments. No date.

HEDGES, ERNEST S. Colloids. 1931.

HOFMAN, H. O. Metallurgy of Zinc and Cadmium. 1922.

JENSEN, H. R. The Chemistry, Flavouring and Manufacture of Chocolate, Confectionery and Cocoa. 1931.

JONES, F. HOPE. Electric Clocks. No date.

KOLTHOFF, I. M. The Colorimetric and Potentiometric Determination of pH. Outline of Electrometric Titrations. 1931.

KRIVOSHEIN, G. C. Simplified Calculation of Statically Indeterminate Bridges. With appendix: Exact Theory of Three-Span Suspension Bridges. 1930.

LOEB, LEONARD B. Fundamentals of Electricity and Magnetism. 1931.

LORENTZ, H. A. Lectures on Theoretical Physics Delivered at the University of Leiden. Volumes 2 and 3. 1927–1931.

BOOK REVIEWS.

BULLETIN OF THE NATIONAL RESEARCH COUNCIL, No. 80, Physics of the Earth-IV, The Age of the Earth, 487 pages, tables, 8vo. Washington, National Research Council. 1931. Price $5.00.

This book binds together data lately gathered by a sub-committee working under the able direction of Adolph Knopf. Charles Schuchert contributes that part that treats with geochronology, or the age of the earth on the basis of sediments and life. It is impossible to read of the sedimentary depositions without sinking a little under the enormous weight of the earth's sediments. 111,000 feet during Paleozoic time, 86,600 feet of Mesozoic and 64,400 feet of Cenozoic, totaling for Europe and America 308,000 feet or more than 58 miles of deposition on mother earth. One's sympathy goes out to the unfortunate fossil that chanced to be caught under a fraction of the load. There are, however, erosional breaks diastems in this record that baffle the geochronicler, give the reader an opportunity to catch breath, and provide a way of escape for a lucky diatom. The precision with which one can write of the time required to lay down these loads is one of the repaying surprises of the book—37 per cent. of the total are sandstones representing 146,000 feet of sediment at 1,000 years a foot or 146,000,000 years, plus shales (44 per cent.) adding 175,000 feet at 1,200 years to the foot or 210,000,000 years together with limestones (19 per cent.) or only 79,000 feet requiring much more time to the foot, 2,500 years, or 197,000,000 years which extends simply to a total of 400,000 feet over a total of 553 million years.

A great deal of evidence has been examined. The denudation of the land mass by rivers, the ratio of clastic deposits, the radio-active disintegrations and the witness of zoölogy all add a testimony to the fact that "the colossal hour-glass of rock destruction on the land and rock formation on the sea floor runs unceasingly."

The problem of determining the age of the ocean is a matter apparently of determining sodium. There was no sodium in the primeval ocean. Only influents are supposed to have added a sodium content to the ocean. The increment has been constant throughout geologic time. Therefore, determining the accumulated saltiness we can peg the age of old man ocean. A convenient figure to remember is (4.1×10^{16} tons.)

Alois F. Kovarik calculates the age of minerals from radioactivity data in part III. This approach to the age of the rocks by studying the isotopes of lead has proved most helpful in what otherwise would be, at best, approximate conjecture. He not only gives the full calculation for the radioactive distinegration of this critical mineral lead, but he also offers formulae for calculating the age of any mineral. Arthur Holmes, also a member of the committee, continues by developing in part IV Radioactivity and Geologic Time. He refers to the early discovery of radioactive minerals, treats the pleochroic halos and reaches the end-product formula:

$$\frac{\text{He}}{\text{U}} \cdot C' \text{ million years}$$

or in the case of fergusonite investigated by Ramsay and Travers

$$\frac{181}{7 \times 5.2 \times 10^{-2}} \text{ million years} = 500 \text{ million years.}$$

A result that arrives, by way of atomic physics, at the same conclusion, reached by the broken ladder of geologic descent, radiates its own implications. Various and many minerals have been cousined in this search. The lead ratios of Europe Asia, North America, and Gonwanaland have been examined as well as the accumulation of helium in minerals and meteorites. The end of this labor leads to a statement that carries us back one step further in our conception of the earth's age. "No more definite statement can therefore be made at present than that the age of the earth exceeds 1,460 million years, is probably not less than 1,600 million years, and is probably much less than 3,000 million years."

Part V, by Ernest W. Brown, brings to bear the astronomical data which can be mustered. Celestial mechanics, however, do not help a very great deal. A review of the earth's eccentricities and inclinations does not contribute much to the discussion. The retardation of rotation by the sun and the moon may have had considerable effect on the lengthening of the earth-day but how to convert this into a measure of time is still out of reach. "The age of the earth is probably of the order of magnitude stated, but that on this evidence (celestial mechanics) it may be one third to three times this age."

HOWARD W. ELKINTON.

FUNDAMENTALS OF ELECTRICITY AND MAGNETISM, By Edward Loeb, Professor of Physics, University of California. xx–432 pages, 8vo, cloth. New York, John Wiley & Sons, Inc., 1931. Price $4.00.

The early investigators who laid the foundation of the quantitative relationships of electricity and magnetism did their work well. With all the recent advances in the atomic and electronic theory of matter, the fundamental concepts which they employed and their derivatives in general remain unchanged. Since the applications of electricity have become widespread, and in many ways commonplace, the student of today may be tempted to lose sight of the very large contribution which these early physicists made to the structure of electrical theory. This historical matter is cleverly condensed by the author in the forty-seven pages of introduction of the first chapter. Therein he provides a general survey of beginnings and the gradual evolution of the science. This is followed by a more detailed chronological account which is conveniently divided into seven periods beginning with 1600 and ending with 1927. With this preliminary outline, when the student proceeds with the discussion of the minutiæ of the subject he does so equipped with a sound general idea of the subject and an appreciation of the full significance of the processes which are developed in the subsequent chapters.

Like other recent texts the subject is approached by a consideration of magnetism and current electricity, the discussion of static electricity being deferred till a later chapter. The subject matter necessarily consists of the familiar topics of texts on electricity and magnetism, but here and there modern atomic and electronic theory of matter is introduced in explaining the phenomena. Electromagnetic effects, transient and alternating current phenomena are treated at ample length and analyzed with convincing clarity, a characteristic which may quite fairly be applied to the text as a whole. Photoelectric and thermionic effects are discussed in considerable detail in the two final chapters. A large number of problems are provided at the end of the volume arranged according to the chapter which they serve to illustrate.

The work is an interestingly treated well-balanced text which should arouse and maintain the interest of the student.

LUCIEN E. PICOLET.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 393. Span-Load Distribution as a Factor in Stability in Roll, by Montgomery Knight and Richard W. Noyes, 16 pages, illustrations. quarto. Washington, Government Printing Office, 1931. Price ten cents.

This report gives the results of pressure-distribution tests made to study the effects on lateral stability of changing the span-load distribution on a rectangular monoplane wing model of fairly thick section. Three methods of changing the distribution were employed: variation in profile along the span to a thin symmetrical section at the tip, twist from $+5°$ to $-15°$ at the tip, and sweepback from $+20°$ to $-20°$. The tests were conducted at the Langley Memorial Aeronautical Laboratory in the 5-foot closed-throat atmospheric wind tunnel.

The rolling moment due to roll at a rate of rotation equivalent to that resulting from the maximum rolling disturbances encountered in normal flight is used as the principal basis of comparison. Normal-force curves are given for the purpose of estimating the general effectiveness of each wing arrangement.

The investigation shows the following outstanding results:

1. Change in profile along the span from the N. A. C. A. 84 at the root to the N. A. C. A.–M2 at the tip considerably reduces lateral instability, but also reduces the general effectiveness of the wing.

2. Washout up to 11° progressively reduces maximum lateral instability.

3. Transition from sweepforward to sweepback gradually reduces the useful angle-of-attack range, but has no clearly defined effect on maximum later instability.

Report No. 397. The Drag Characteristics of Several Airships Determined by Deceleration Tests, by F. L. Thompson and H. W. Kirschbaum, 15 pages, illustrations, quarto. Washington, Government Printing Office, 1931. Price ten cents.

The results of deceleration tests conducted for the purpose of determining the drag characteristics of six airships are given herein. The tests were made during the past few years with airships of various shapes and sizes belonging to the Army, the Navy, and the Goodyear-Zeppelin Corporation. In each instance a representative of the National Advisory Committee for Aeronautics coöperated with the organization to which the airship belonged to conduct the tests. Although the deceleration tests with the U. S. S. "Los Angeles" have been previously reported, the final results obtained with that airship are included herein for comparison.

Drag coefficients for the following airships are shown: Army "TC-6," "TC-10," and "TE-2"; Navy "Los Angeles" and "ZMC-2"; Goodyear "Puritan." The coefficients vary from about 0.045 for the small blunt airships to 0.023 for the relatively large slender "Los Angeles." This variation may be due to a combination of effects, but the most important of these is probably the effect of length-diameter ratio.

Report No. 399. Flame Movement and Pressure Development in an Engine Cylinder, by Charles F. Marvin, Jr., and Robert D. Best, 12 pages, illustrations, quarto. Washington, Government Printing Office, 1931. Price ten cents.

This investigation, which was carried out at the Bureau of Standards at the request and with the financial assistance of the National Advisory Committee for Aeronautics, describes a visual method for making stroboscopic observations, through a large number of small windows, of the spread of flame throughout the combustion chamber of a gasoline engine. Data, secured by this method on a small engine burning gaseous fuels, are given to show the effects of mixture ratio, spark advance, engine speed, charge density, degree of dilution, compression ratio, and fuel composition on flame movement in the cylinder. Partial indicator diagrams showing pressure development during the combustion period are included. Although present knowledge is not sufficient to permit qualitative evaluation of the separate effects on flame movement of chemical reaction velocity, thermal expansion of burned gases, resonance, turbulence, and piston movement, the qualitative influence of certain of these factors on some of the diagrams is indicated.

R.

PUBLICATIONS RECEIVED.

The Physics of High Pressure, by P. W. Bridgman, Ph.D., 398 pages, illustrations, plates, 8vo. New York, The Macmillan Company, 1931.

Johann Kepler, 1571–1630, A Tercentenary Commemoration of His Life and Work, a series of papers prepared under the auspices of The History of Science Society, 133 pages, diagrams, 8vo. Baltimore, The Williams & Wilkins Company, 1931. Price $2.50.

Examination of Water, Chemical and Bacteriological, by William P. Mason, 224 pages, tables, diagrams, 8vo. New York, John Wiley & Sons, Inc., 1931. Price $3.00.

Nucleic Acids, by P. A. Levene and Lawrence W. Bass, 337 pages, diagrams, 8vo. New York, The Chemical Catalog Company, Inc., 1931. Price $4.50.

Chemical Engineering Catalog, 1931, sixteenth annual edition, 1017 pages, illustrations, tables, folio. New York, The Chemical Catalog Company, 1931.

National Advisory Committee for Aeronautics, Technical Notes: No. 395, Penetration and Duration of Fuel Sprays from a Pump Injection System, by A. M. Rothrock and E. T. Marsh, Langley Memorial Aeronautical Laboratory, 16 pages, diagrams, tables, quarto, Washington, Committee, 1931. No. 397, The Aerodynamic Characteristics of Six Commonly Used Airfoils over a Large Range of Positive and Negative Angles of Attack, by Raymond F. Anderson, 4 pages, tables, diagrams, quarto, Washington, Committee, 1931. No. 398, The Effect of Slots and Flaps on the Lift and Drag of the McDonnell Airplane as Determined in Flight, by Hartley A. Soule, Langley Memorial Aeronautical Laboratory, 12 pages, tables, diagrams, quarto, Washington, Committee, 1931.

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